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OCTOBER 1958 VOLUME 3 NUMBER 30

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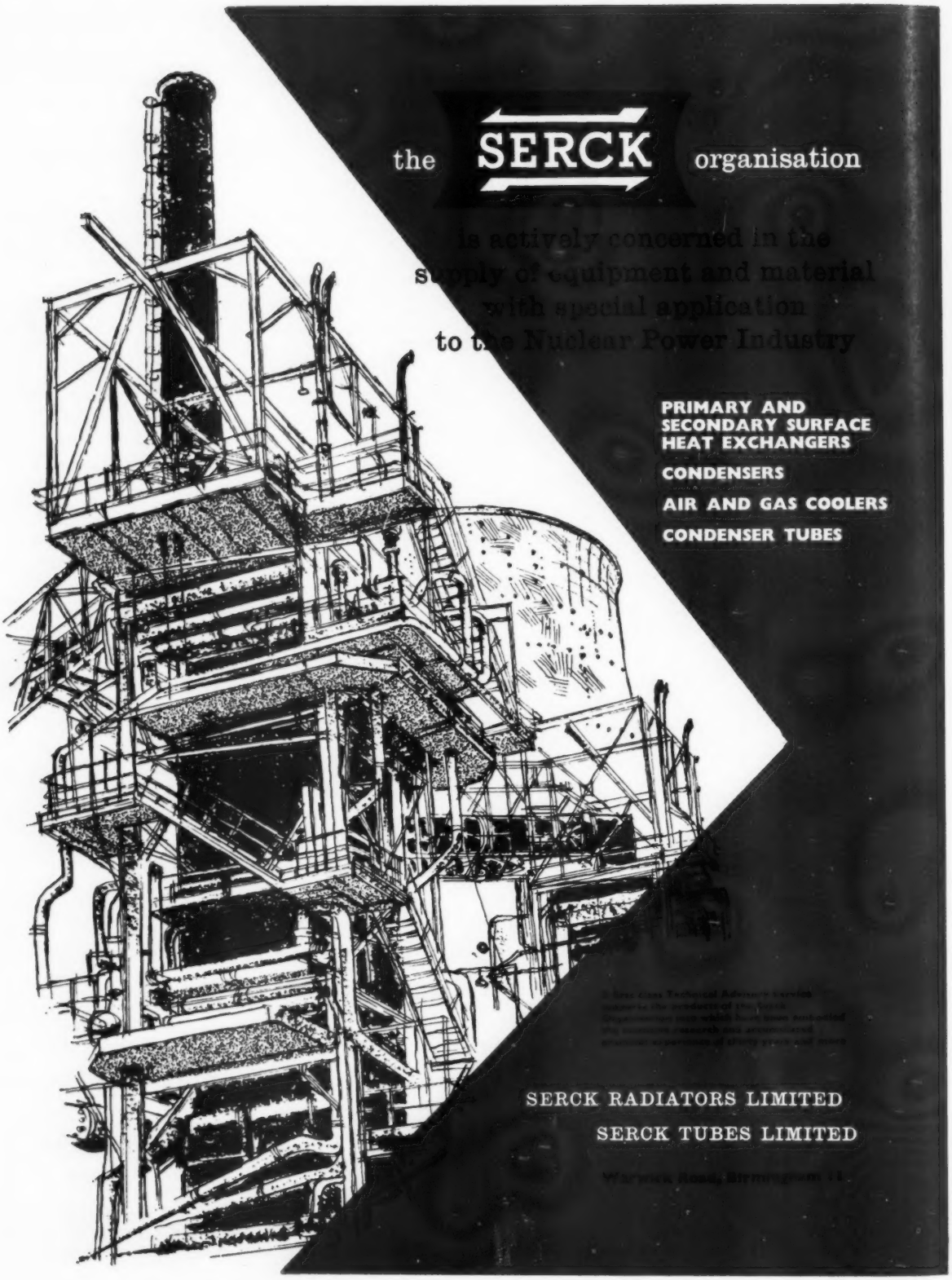
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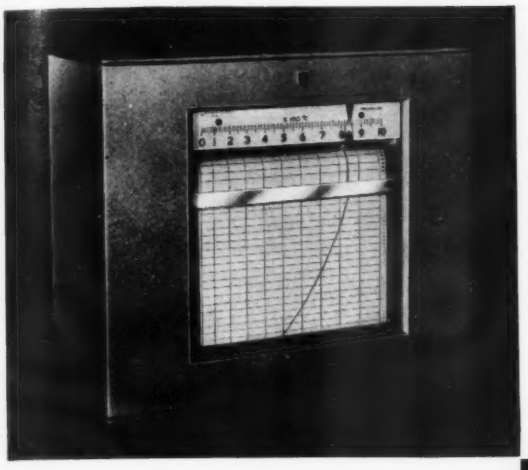

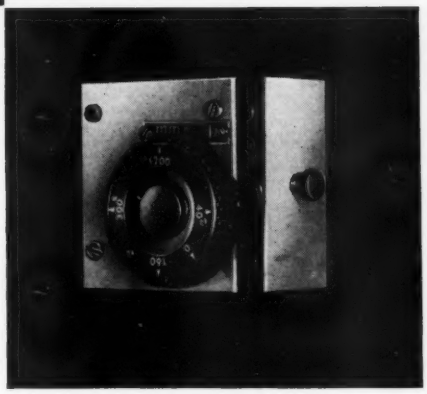

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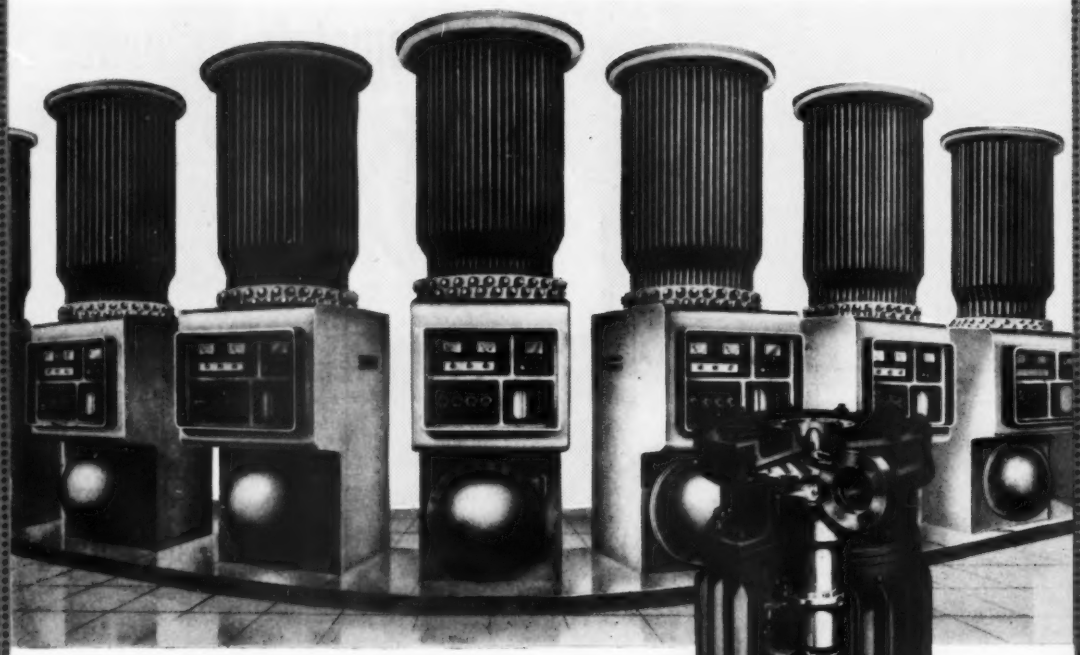

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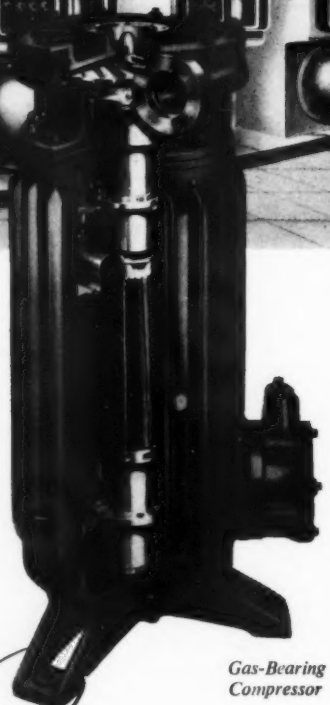

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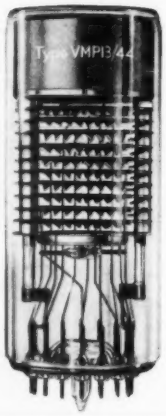

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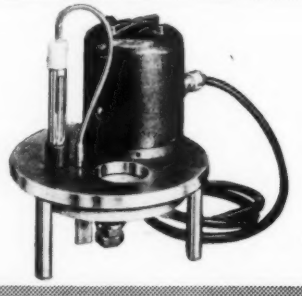

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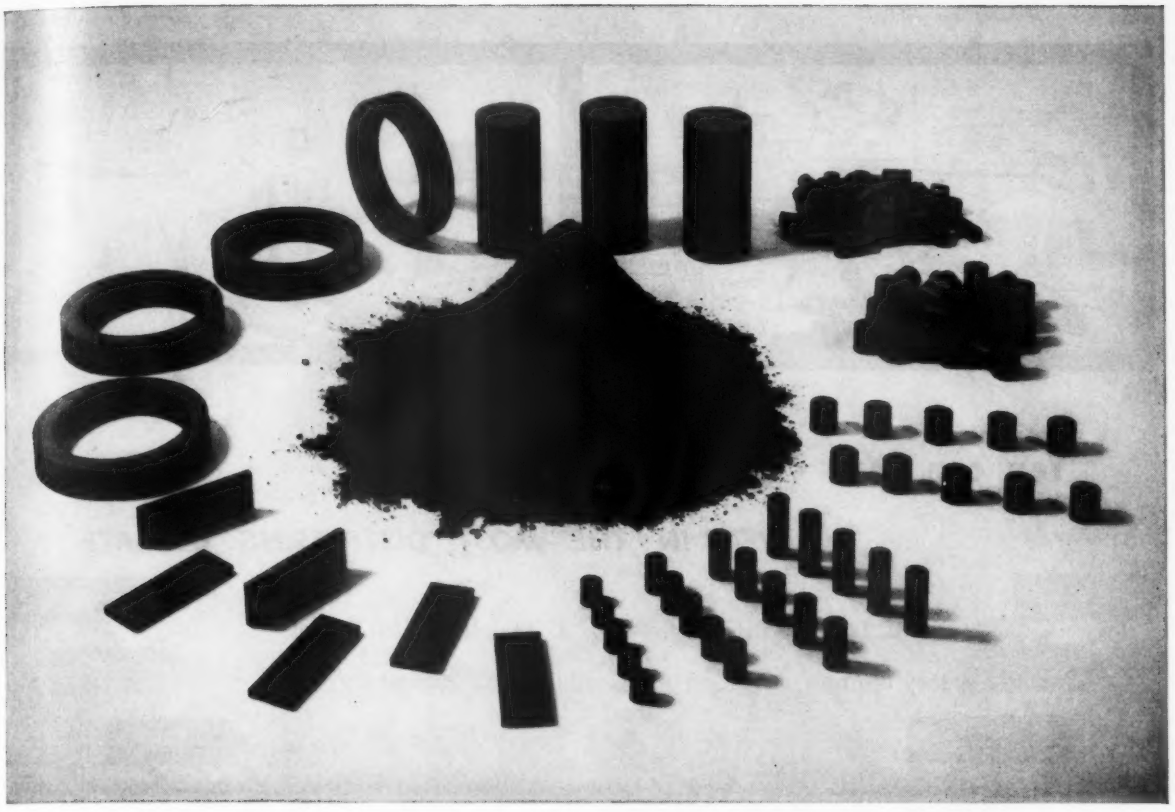

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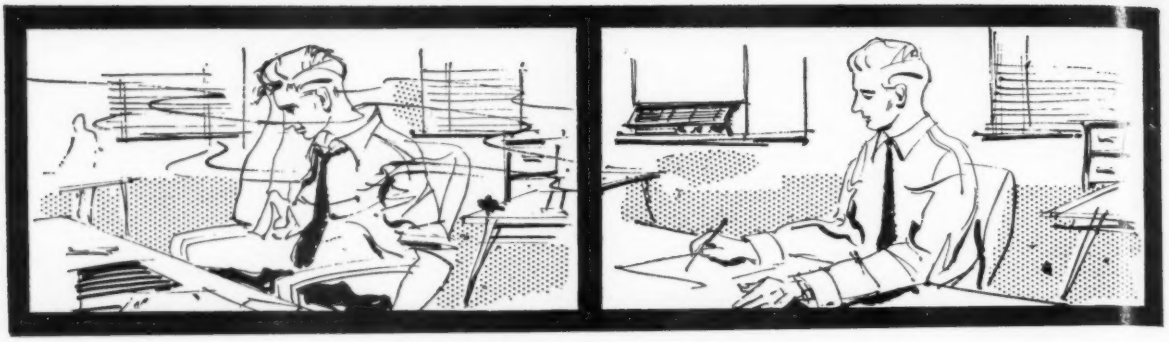

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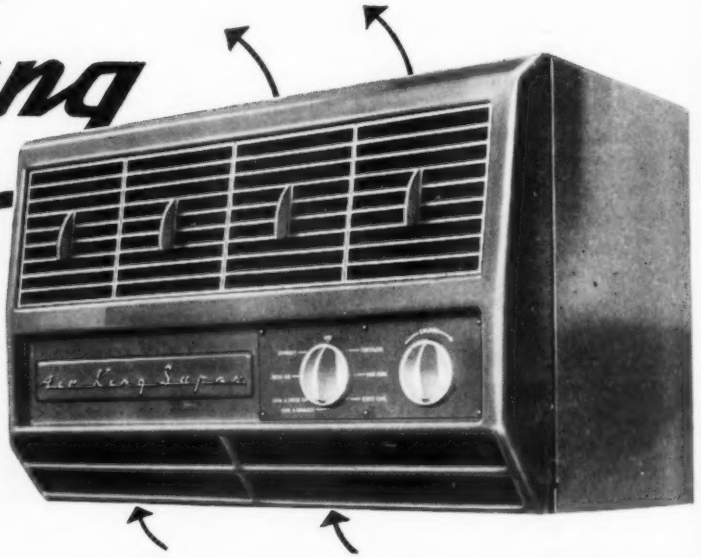

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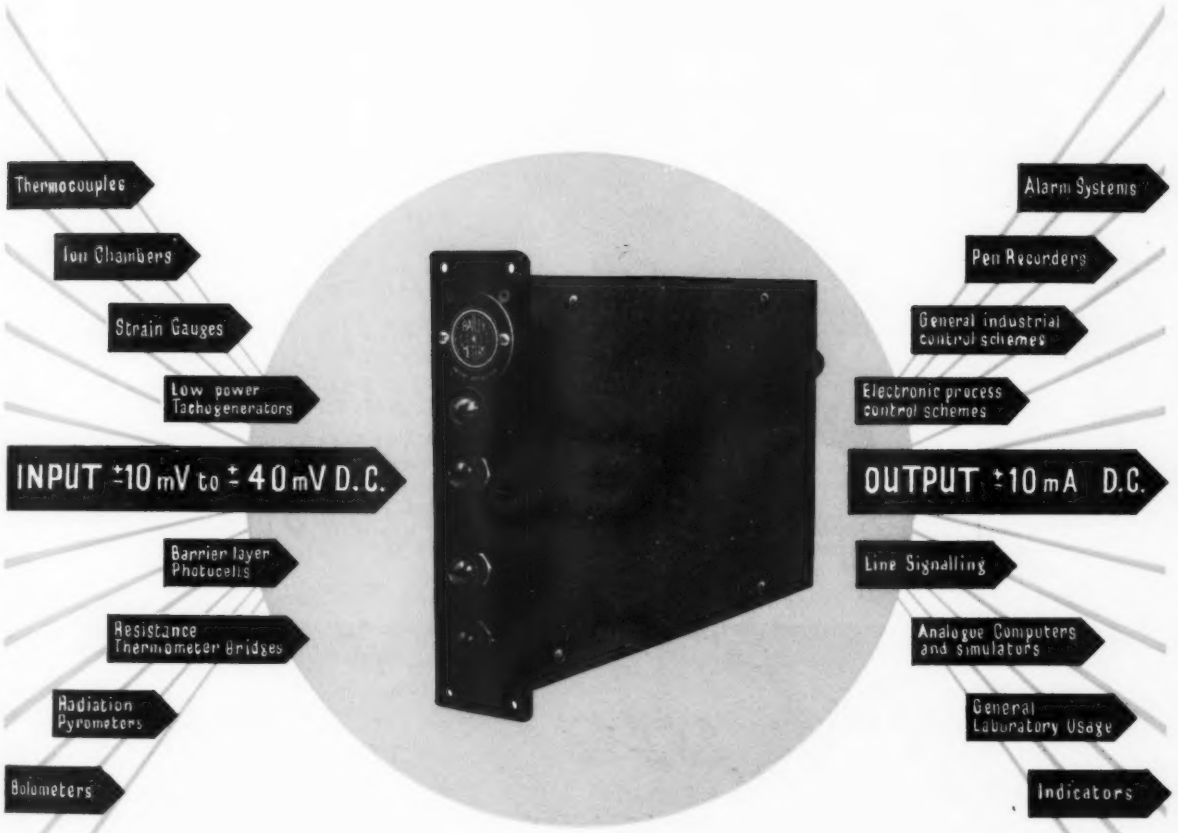

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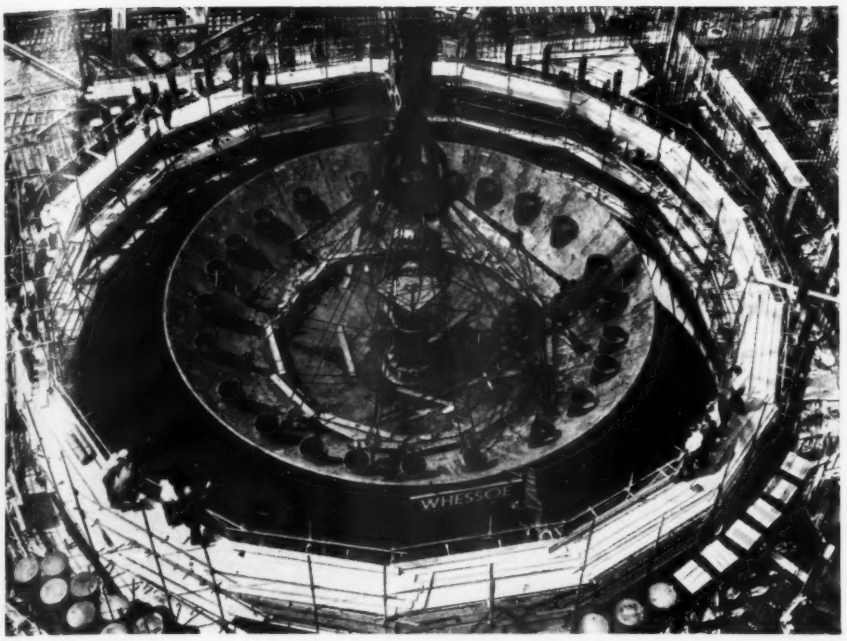

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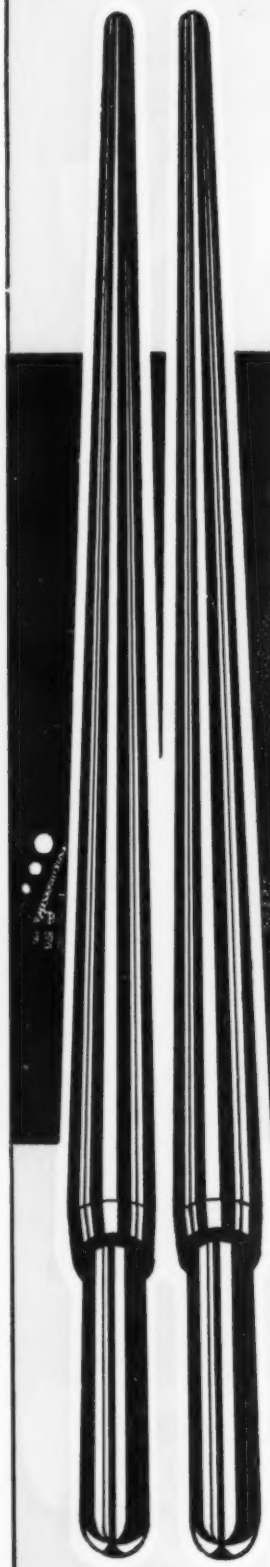

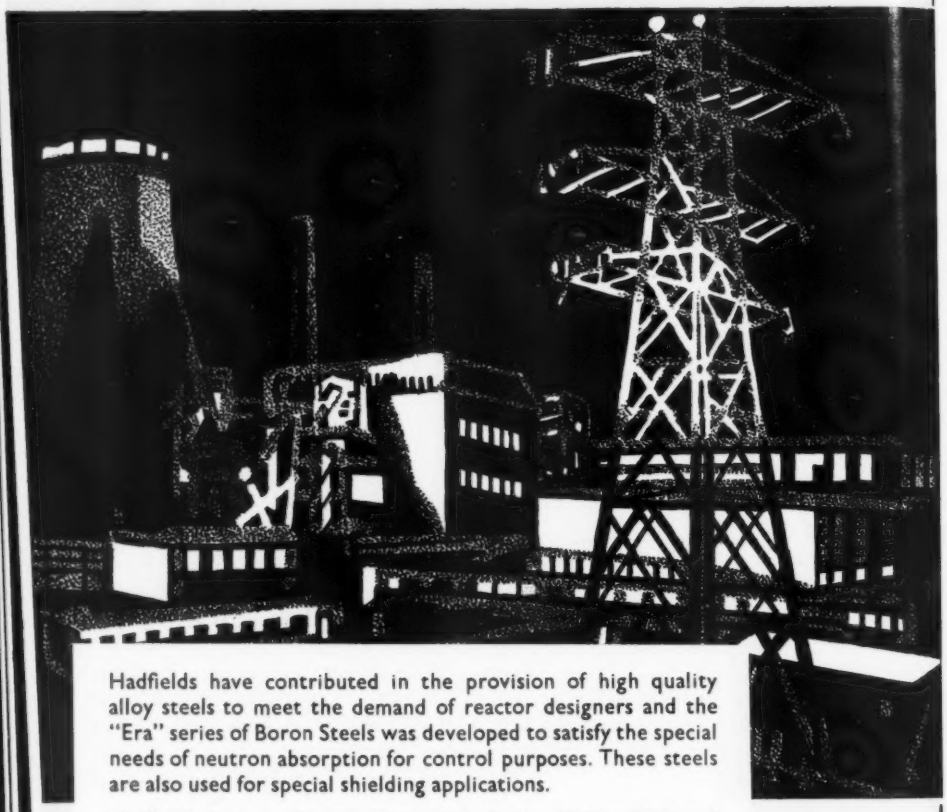

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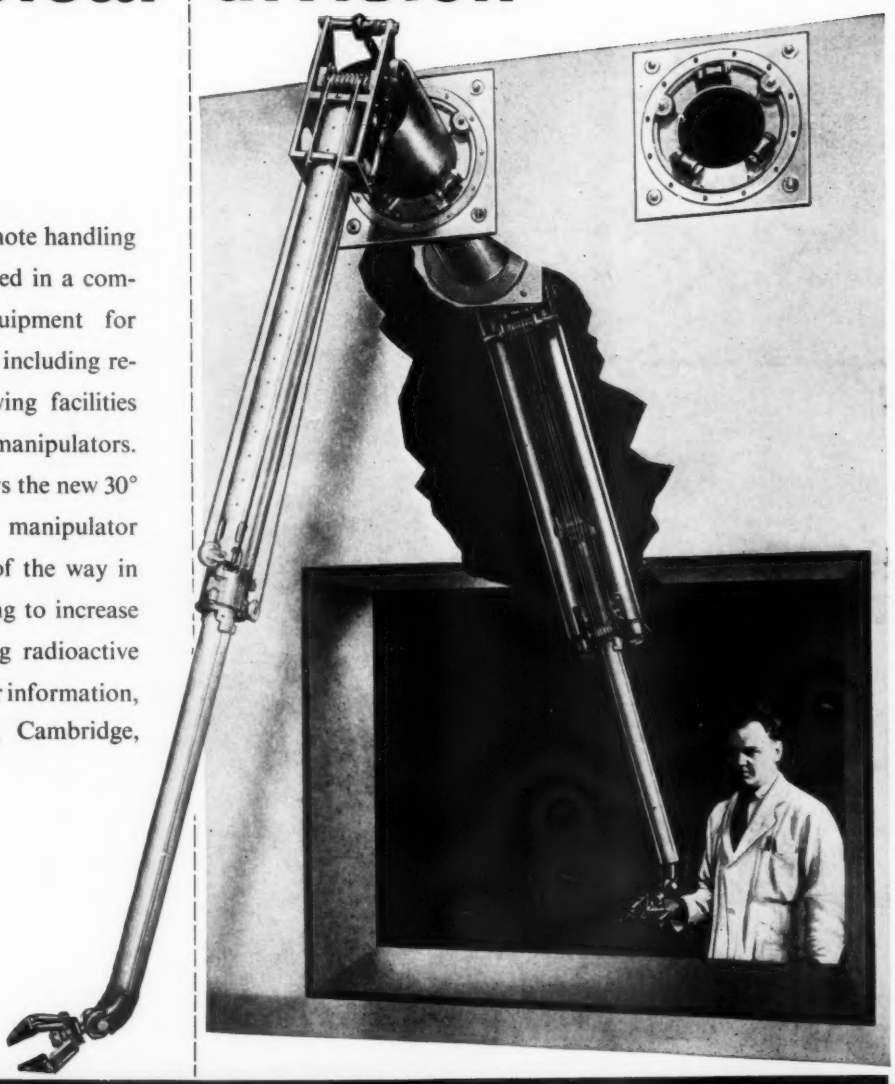

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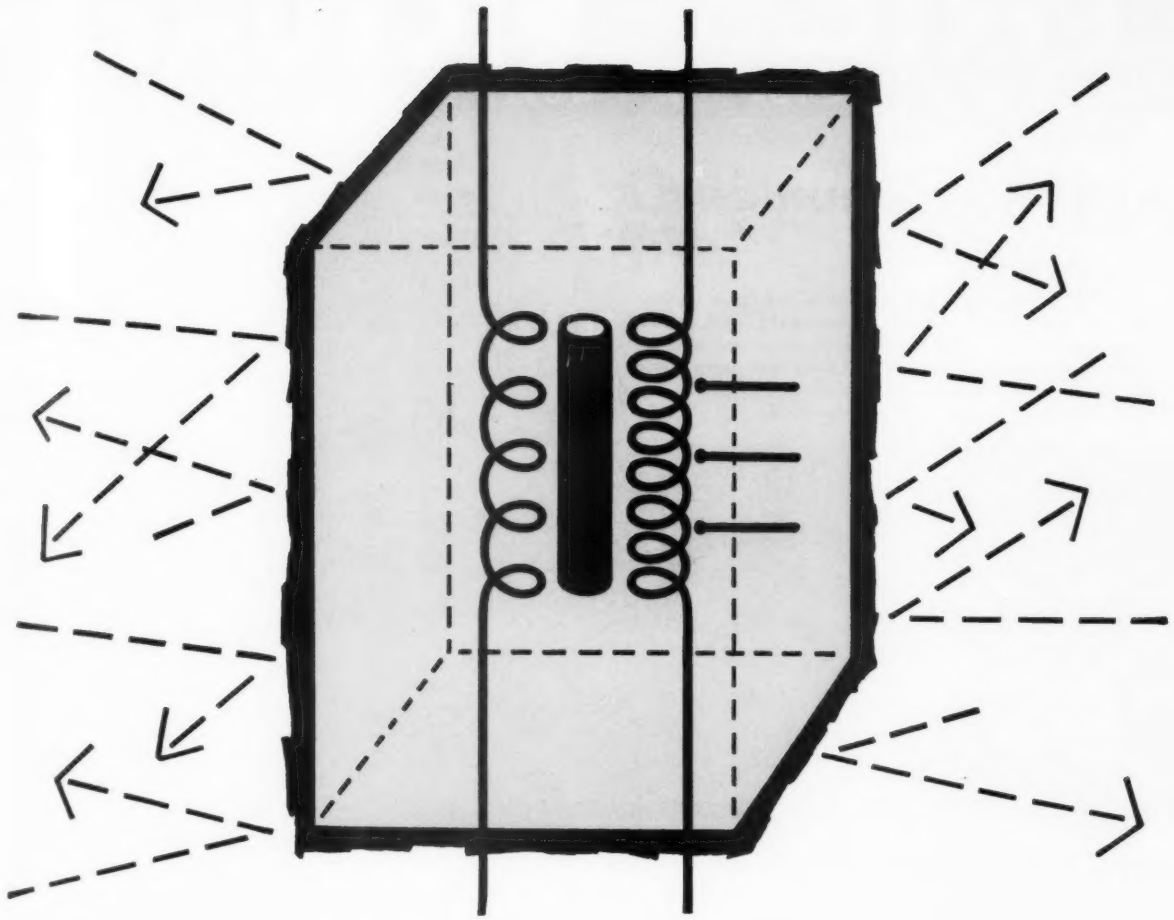

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Reliable, accurate reactor instruments for use as individual components in "customized" systems . . . reactor instruments to ORNL specifications, or to your own specialized designs. Perhaps best of all is that we're in production and can ship all these and many other types. Bring your reactor instrument problems to Victoreen, the specialists in reactor instruments and instrumentation.

Model 751 (ORNL Q1593)
DD-2 Non-Overload Linear Amplifier for scintillation spectrometry, reactor control, etc. and other applications requiring high gain, fast resolution, good linearity, and fast overload recovery.

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One microsecond
designed for counting
nuclear detectors.
pulses at high rates
low coincidence
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Logarithmic Count Rate Meter. Wide range, five decade instrument for use with all types of radiation detectors. Range 10 to 1,000,000 counts per minute.

Model 872A (ORNL Q1326)
AID Linear Amplifier. Amplifies low level signal pulses from radiation detectors such as ionization chambers, proportional and scintillation counters.

Model 695 (ORNL Q1192)
Single Channel Differential Analyzer. A differential pulse height analyzer for separating pulses of varying amplitudes.

Model 883
Ultra-Stable Hi-Voltage Power
Stable and regulated power
of all types for precision
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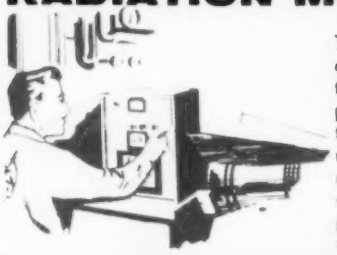
and proportional counting
ously variable over wide
voltages.

RADIATION MONITORING



To detect, measure, record or control radiation of almost any type or intensity . . . with complete systems to AEC specifications — that's part of Victoreen's radiation monitoring story. So no matter what your radiation monitoring problem, it will probably pay you to check with Victoreen first.

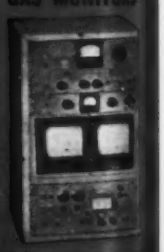
(ORNL Spec. 684)
Flexible, fully proven remote area monitoring systems to AEC requirements for radiation monitoring from a single control center.

Portable continuous air
monitoring units to
specifications.

A reliable monitoring system based on MTR design at Idaho Falls for detection of fission product activity in coolant stream.

Fast and thermal neutron monitoring systems designed for bulk shielding and dosimetry studies.

For monitoring radioactive liquids in pipes, pools and streams or other locations.



Designed for continuous
of radioactive stack gases
built-in alarm system to
thermal control circuits.

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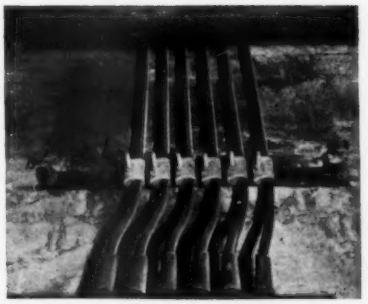
TELCON p.v.c. insulated and sheathed single wire armoured and p.v.c. sheathed cables, terminated with TELCON glands type 'G' and p.v.c. shrouds are used in the East Greenwich Works of the South Eastern Gas Board.

When TELCON cables are sheathed and insulated with p.v.c.

I.C.I. 'Corvic' is used

I.C.I. 'CORVIC' p.v.c. polymers are backed by the finest research and technical service in the country. If you are interested in the use of p.v.c., if you would like to know more about its applications, get in touch with I.C.I. Their service is at your disposal.

One of the many important organisations which uses 'Corvic' is The Telegraph Construction and Maintenance Co. Limited. 'Corvic' is widely used in the manufacture of TELCON cables.



'CORVIC'

'Corvic'i. the registered trade mark for the p.v.c. polymers manufactured by I.C.I.

ICI IMPERIAL CHEMICAL INDUSTRIES LIMITED · LONDON · S.W.1

PC.18

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Under pressure, we'll admit...

...there's quite a lot we know about the behaviour of pipes. Teddington Bellows Expansion Joints are designed and engineered to take up and absorb expansion, contraction and lateral movement of piping in a wide variety of industries.

After Teddington Bellows have been butt-welded from highly finished cold rolled stainless steel sheets, convolutions are introduced to give the bellows their characteristic flexibility under pressure.

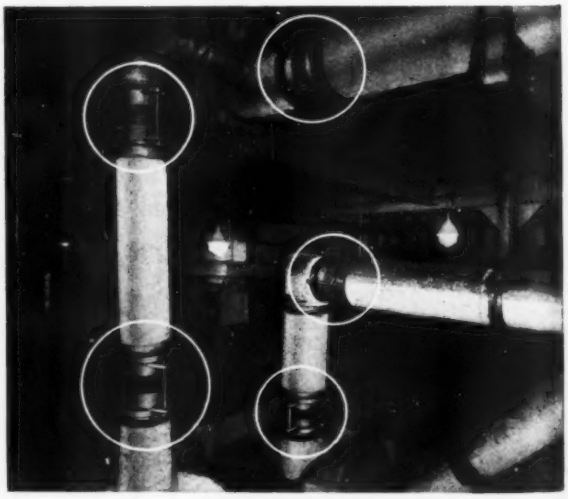
Nuclear, chemical, marine and gas engineers acknowledge their efficiency and superiority over many older forms of expansion joints.

Wherever pipe-work is subjected to vibration or movement in any direction, a Teddington Bellows with a suitable end-fitting will solve the problem.

LET OUR ENGINEERS ADVISE ON YOUR EXPANSION PROBLEMS

Send for our brochure No. R 104

Teddington Bellows are produced in technical collaboration with the Solar Aircraft Co. U.S.A.



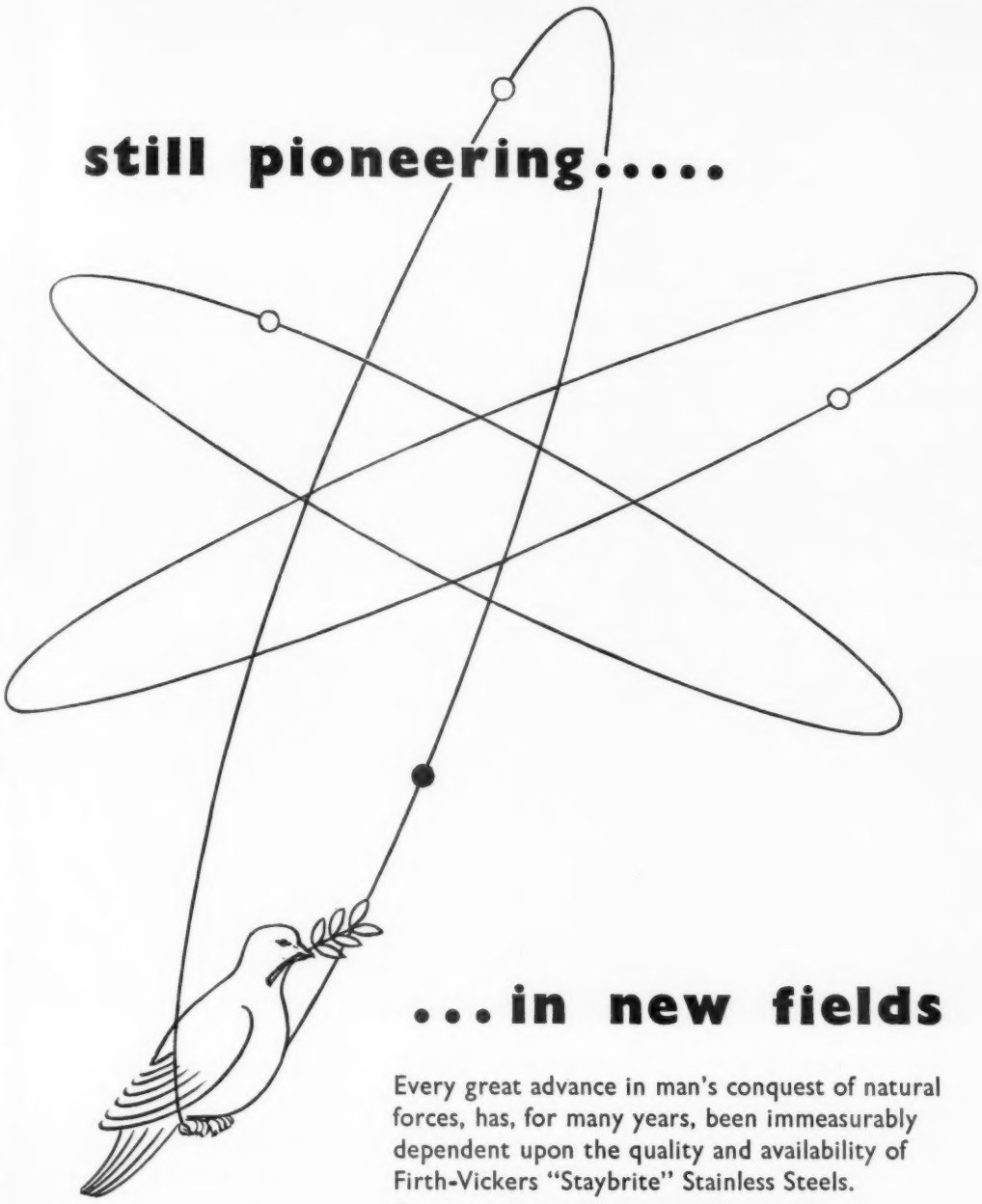
pipes on the move prefer

TEDDINGTON BELLOWS

EXPANSION JOINTS

TEDDINGTON AIRCRAFT CONTROLS LTD
INDUSTRIAL BELLOWS DIVISION
Ammanford, Carmarthenshire. Tel: Ammanford 455

still pioneering.....



...in new fields

Every great advance in man's conquest of natural forces, has, for many years, been immeasurably dependent upon the quality and availability of Firth-Vickers "Staybrite" Stainless Steels.

The special engineering problems of this Nuclear Age depend upon the steels which Firth-Vickers have developed and are still developing in the corrosion, heat and creep-resisting fields.

FIRTH - VICKERS STAINLESS STEELS LTD., SHEFFIELD

TELEPHONE: SHEFFIELD 42051

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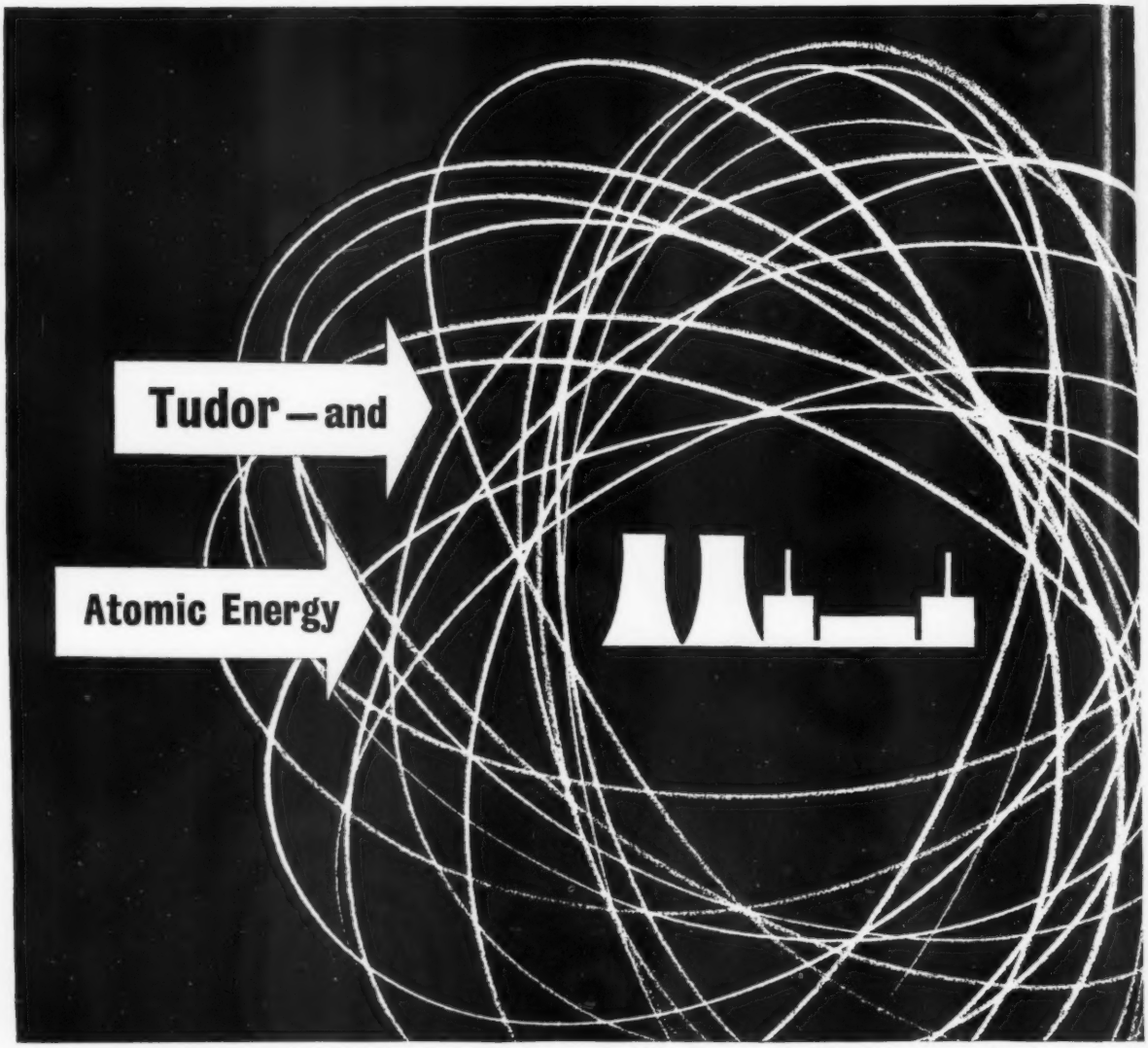

Tudor specialize in the design and supply of batteries and allied equipment for atomic energy establishments. Contracts for battery equipment include 240V Station batteries, 110V Switch Closing batteries, 50V Tripping batteries and 50V Control batteries complete with charge and control equipment and distribution boards for each of these Power Stations —

CALDER HALL 'A'
CALDER HALL 'B'
CHAPEL CROSS
DOUNREAY

Supplied under sub-contract from A. Reyrolle & Co. Ltd; The English Electric Co. Ltd; Brush Electrical Engineering Co. Ltd (a member of the Brush Group)

T.159

Tudor BATTERIES

THE TUDOR ACCUMULATOR COMPANY LTD. 137 VICTORIA STREET, LONDON SW1 TELEPHONE: TATE GALLERY 0307
Works: Dukinfield, Cheshire. Telephone: Ashton-under-Lyne 1651

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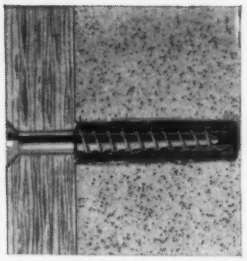
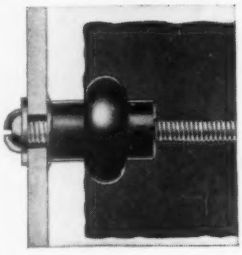
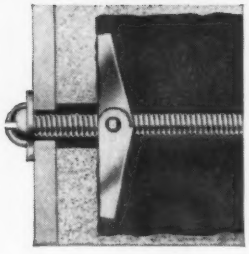
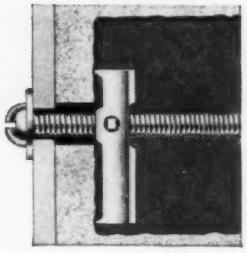
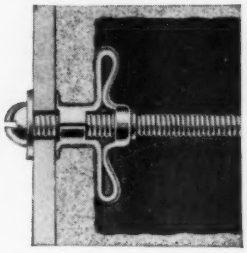
SOLID OR CAVITY MATERIALS





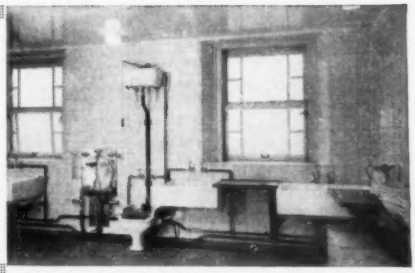




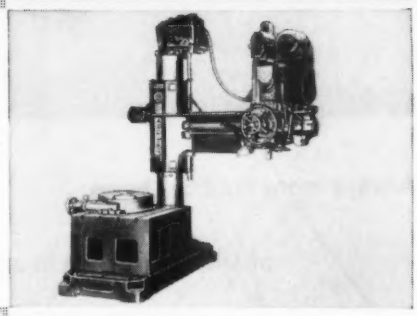


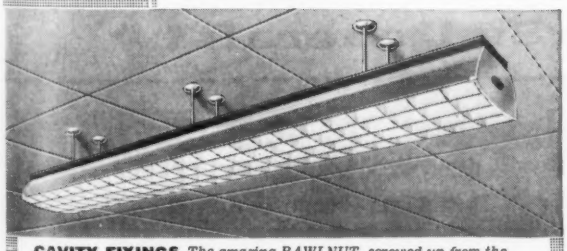
Rawlplug fixing devices save you time and money

SCREW FIXINGS
Use the famous RAWLPLUG for neat, firm fixings in brick, stone, etc. All sizes for up to $\frac{3}{4}$" diameter Coach Screws. Rawlplugs are waterproofed and unaffected by climatic conditions.



BOLT FIXINGS
For bolting down machines, light or heavy, use RAWLBOLTS, a dry fixing that grips by expansion. No cold chiselling, no waiting for cement to harden. Sizes up to 1" bolt diameter.





CAVITY FIXINGS *The amazing RAWLNUT, screwed up from the front, forms its own rivet head behind the material—airtight, watertight, vibration-proof, squeak-proof! For all thin or hollow materials.*

Fixing methods that served well enough in bygone days fall far short of modern standards of efficiency, when an average machine can be safely bolted down *and in operation* within an hour or so of arrival!

Rawlplug Fixing Devices always save time and therefore money, for it is a simple *fact* that on *every* screw and bolt fixing job, in solid *or* cavity materials, you'll make strong, absolutely safe fixings in *far less time than by any other method.*

You can easily prove this for yourself. The first step is to write for full details of the 21 different types of Rawlplug Fixing Devices. Write us now —and if after studying our literature, you have any difficulties about a particular problem, our Technical Service specialists will be delighted to advise you without obligation.

RAWLPLUG

FIXING DEVICES

THE RAWLPLUG COMPANY LTD
CROMWELL ROAD, LONDON, S.W.7

B591

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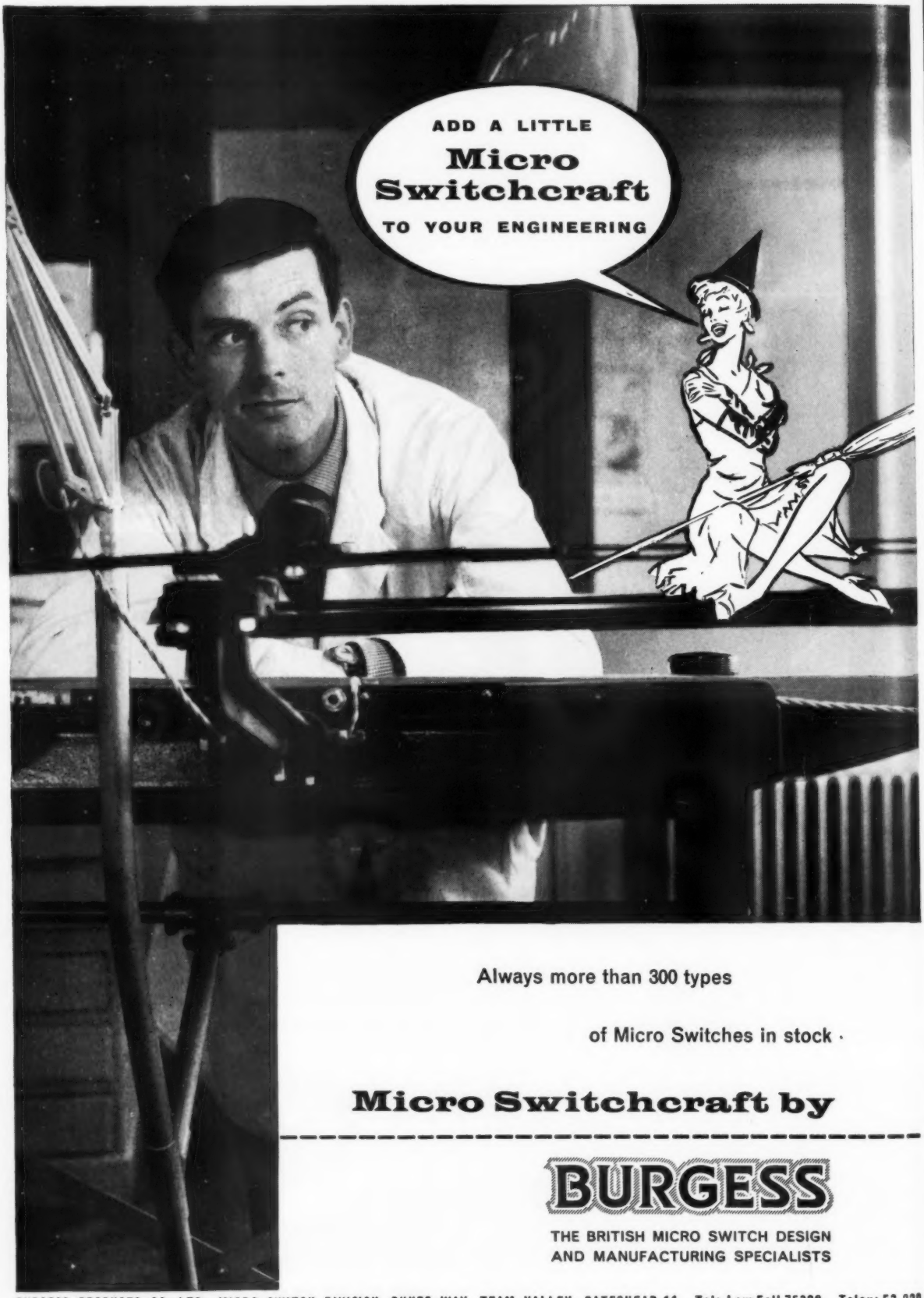

Always more than 300 types

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THE BRITISH MICRO SWITCH DESIGN
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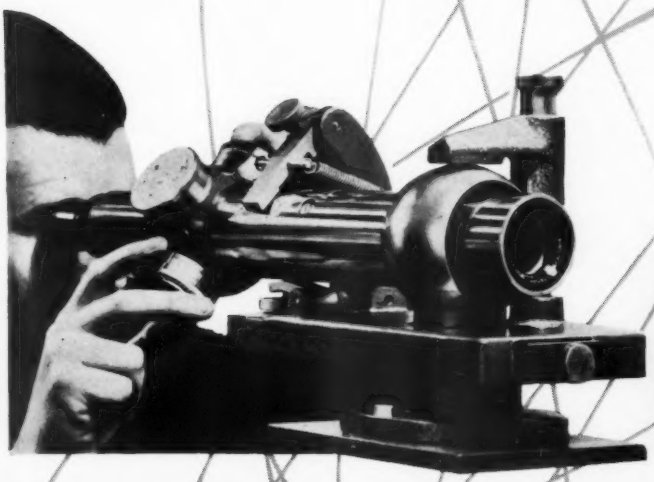
DIDO



TAYLOR-HOBSON

MICRO ALIGNMENT TELESCOPE

ZETA

BEPO

Used by the United Kingdom Atomic Engineering Research Establishment in the construction of Experimental Nuclear Reactors and the associated Projects ZETA, BEPO, ZEUS, ZEPHYR, DIDO and PLUTO. Also used by the leading manufacturing groups in the construction of Nuclear Power Stations, of the Power Supply Plan in Great Britain.

✳ **PROTECT PERSONNEL** with Kershaw Dosimeters as supplied to the British Government.

A Division of RANK PRECISION INDUSTRIES LTD.

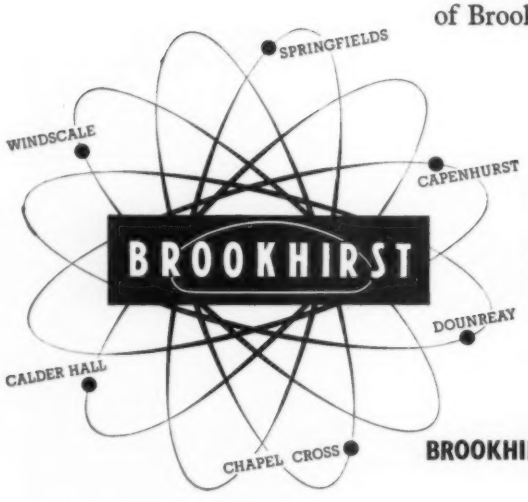
TAYLOR TAYLOR & HOBSON LTD., LEICESTER, ENGLAND

AT28

BROOKHIRST

for BRADWELL

Under sub-contract to A. Reyrolle & Co. Ltd., Brookhirst motor starters are being supplied for vitally important plant at Bradwell, the nuclear power station being built by the Nuclear Power Plant Co. Ltd., for the Central Electricity Generating Board. Being chosen for this notable installation is yet another proof of Brookhirst leadership in motor control in the nuclear field.



As specialised sub-contractors Brookhirst have also been called upon to supply very large quantities of motor control gear for the United Kingdom Atomic Energy Authority's establishments.

BROOKHIRST SWITCHGEAR LTD., NORTHGATE WORKS, CHESTER

A METAL INDUSTRIES GROUP COMPANY

CVS-58

RARE EARTHS AS NUCLEAR POISONS

Cost and availability are no longer problems

a report by LINDSAY

Significant developments in the cost and availability of the neutron absorbing rare earths are redirecting the attention of control rod designers to the use of these materials as poisons in nuclear reactors.

Early interest in the rare earths was centered in europium because of its superb neutron absorbing properties and extended life. At that time, *all* the high cross section rare earths were scarce and expensive, and the metallurgical problems were relatively unexplored.

PRODUCTION FROM ION EXCHANGE

Since then, considerable experimental work has been devoted to development of practical fabricating techniques and the improvement of separation processes. Lindsay pioneered the first commercially installed ion exchange plant for the production of rare earth oxides in purities up to 99.99%.

Now, more than 100 columns with large production units of eighteen inch and sixty inch diameters are in continuous operation at the Lindsay plant. All the important neutron absorbing rare earths are now available, not only as the oxide which can be custom made with regard to density and particle size, but also as the boride, disilicide, or metal.

One important by-product of the advances in separation technology is that several of the rare earth absorbers have become common materials. The prices of oxides of gadolinium, samarium, erbium, dysprosium and europium have all tumbled sharply. Only europium is priced above $1 per gram; samarium and gadolinium are but a few cents per gram.

We know of course that europium is the most effective control rod material, but because of its scarcity, it will always be the most expensive rare earth absorber. Control rod designers now need to consider price, as well as properties, when selecting rare earth materials as control rod poisons.

Except in high flux reactors requiring few control rods, it is uneconomic to use europium as a primary poison; most commercial reactors do not need it except for its ability to absorb epithermal neutrons. Therefore, we suggest that control rod designers concerned with fluxes of about 2×10^{13} consider gadolinium as their primary poison, with samarium, dysprosium, erbium, or europium as additions to achieve desired rod worth. *Where both cost and performance are factors, the rare earths are no longer exotic, but actually superior to other materials.*

Furthermore, the prices quoted for certain mixtures of the rare earths may be well below those quoted for each material separately.

AMPLE CAPACITY TO MEET DEMAND

Lindsay has expanded production facilities and has ample capacity to meet anticipated demand for neutron poisons in the foreseeable future. Our technical staff is familiar with both control rod and rare earth separation technologies, and is available to help you select the most economical mixture of materials.

We have a wealth of technical data and ideas relating to the use of various rare earths in control rods, some of which is contained in our brochure "Rare Earths as Poisons in Nuclear Reactors." A copy is yours for the asking.

THORIUM . . . *a superior fertile material*

Lindsay is the world's largest producer of *both* rare earth and thorium chemicals. Thorium and thorium oxides are being used and proposed more and more in new reactors in spite of the temptation to use uranium in order to capitalize on the temporary high buy back price for Pu. Thorium materials, particularly the metal, can operate at higher thermal conditions than their uranium counterparts, and show a somewhat higher thermal conductivity. The η for U^{233} is much higher at thermal neutron energies than η for any other fuel; the Th-U^{233} cycle is the best hope for breeding in thermal reactors.

Among the materials produced by American Potash & Chemical Corporation which may be of interest to you are Cesium, Rubidium, Boron and Lithium.

PLEASE ADDRESS INQUIRIES TO

TRONA

LINDSAY CHEMICAL DIVISION

American Potash & Chemical Corporation

298 ANN STREET, WEST CHICAGO, ILLINOIS

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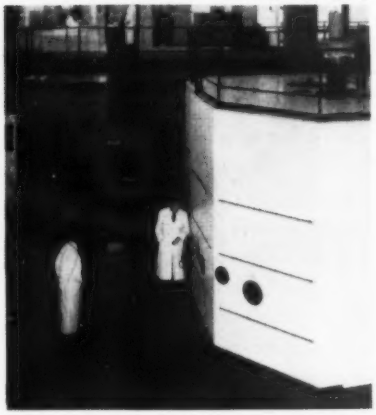
THE PEACEFUL ATOM

Improved atomic power plants for Europe

New Power Reactors Now Ready for Continent Where Nuclear Science Was Born

Since the time when nuclear fission was discovered in Europe, men all over the world have helped in the long, hard task of putting the atom to work for humanity. In America, Atomics International is a pioneer in this endeavor. This work began in 1946, by bringing



RESEARCH FOR SCIENTIFIC PROGRESS
Research Reactors like this one at the University of Frankfurt are used for studies in science, medicine, and industry.

together some of the very few men who had practical nuclear experience in those days. Today Atomics International has grown into a leading producer of nuclear reactors—for America, and for the world.

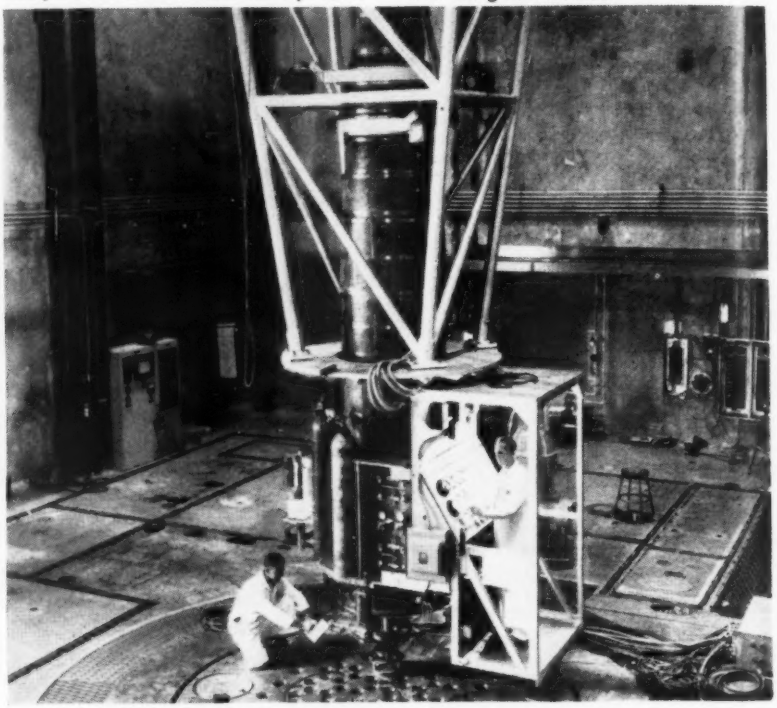
Designs already tested

To help in the power expansion plans of Europe, Atomics International has two proven types of reactor available for immediate construction. In addition, several advanced concepts are under intensive study. Working with the U. S. Atomic Energy Commission, Atomics International built a Sodium Graphite Reactor and an Organic Moderated Reactor. Both are performing excellently. Electricity from the Sodium Reactor Experiment is being supplied to the public in California, and a 75-megawatt power station based on this reactor is being constructed in Nebraska. An Organic Moderated Reactor plant for the American city of Piqua, Ohio, is scheduled for early construction. OMR power stations in the range of 100 to 150 mw are presently under consideration by both American and European utilities. The OMR is also highly suitable to propel merchant ships.

In addition, Atomics International is engaged in the development of the Advanced Epithermal Thorium Reactor for a group of fifteen American utilities, with a plant-capacity target of 200 mw.

Customers in many countries

AI has built research reactors for: the Danish Atomic Energy Commission, near Copenhagen; the University of Frankfurt, West Germany; the Institute for Nuclear Research, West Berlin; the Atomic Energy Institute of Japan, near Tokyo. Another for the Politecnico of Milan, Italy, is nearly finished. A number of small, low-cost reactors for University training and research are also being constructed.



POWER FOR ECONOMIC DEVELOPMENT
The Sodium Reactor Experiment in California has demonstrated the Sodium Graphite type of reactor to be practical and efficient for the production of electrical power.

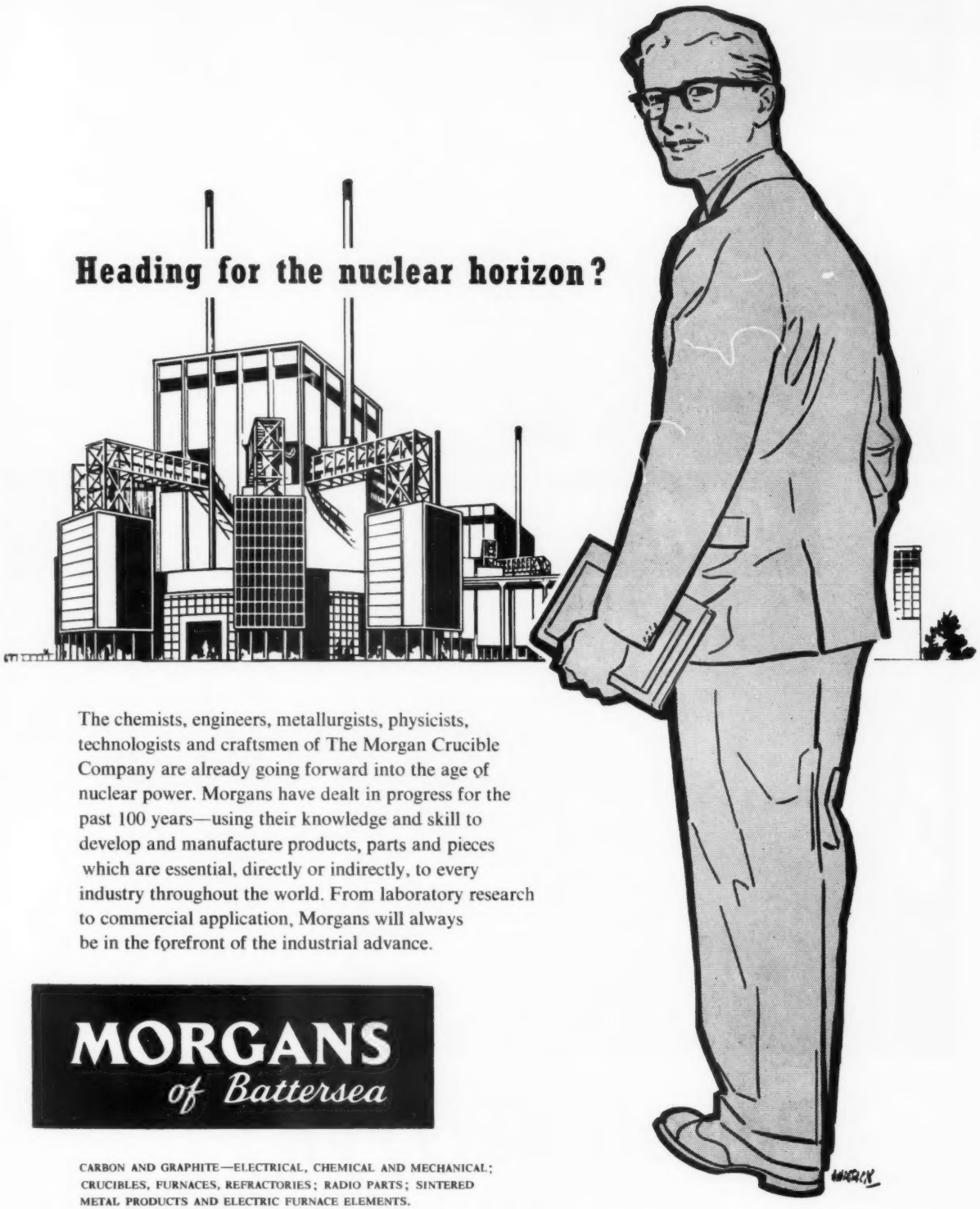
Associates in Europe

In association with the prominent West German manufacturing company DEMAG, Atomics International has formed the jointly owned subsidiary INTERATOM, headquartered in Duisburg. We also have a technical assistance agreement with ASEA of Vasteras, Sweden, the international electrical firm with offices in 50 countries. For more information, please contact: ATOMICS INTERNATIONAL, Canoga Park, California, U.S.A. Cable address: ATOMICS.

ATOMICS INTERNATIONAL
A DIVISION OF NORTH AMERICAN AVIATION, INC.
PIONEERS IN THE CREATIVE USE OF THE ATOM

Other Offices in: Washington, D.C., U.S.A.; Geneva, Switzerland
Affiliated with: Interatom, Duisburg, West Germany

Heading for the nuclear horizon?



The chemists, engineers, metallurgists, physicists, technologists and craftsmen of The Morgan Crucible Company are already going forward into the age of nuclear power. Morgans have dealt in progress for the past 100 years—using their knowledge and skill to develop and manufacture products, parts and pieces which are essential, directly or indirectly, to every industry throughout the world. From laboratory research to commercial application, Morgans will always be in the forefront of the industrial advance.

MORGANS *of Battersea*

CARBON AND GRAPHITE—ELECTRICAL, CHEMICAL AND MECHANICAL; CRUCIBLES, FURNACES, REFRACTORIES; RADIO PARTS; SINTERED METAL PRODUCTS AND ELECTRIC FURNACE ELEMENTS.

THE MORGAN CRUCIBLE COMPANY LIMITED, BATTERSEA CHURCH ROAD, LONDON, S.W.11. BAT: 8822
MCC 124/A

A machine shop specially established for machining graphite under "Clean Conditions" is now in operation at our Hayes Works. This new department supplements our already extensive facilities for machining commercial graphite and is fully equipped with specialised plant for high precision work. It is capable of producing all types of graphite components for nuclear purposes.

GRAPHITE MACHINING

These photographs show the graphite for the NATURAL URANIUM GRAPHITE MODERATED EXPONENTIAL EXPERIMENT at Imperial College, London being machined in the new department. Further facilities for precision machining of full production quantities under "Clean Conditions" are now being installed.

Powell Duffryn

CARBON PRODUCTS LIMITED

DELANIUM CARBON & GRAPHITE

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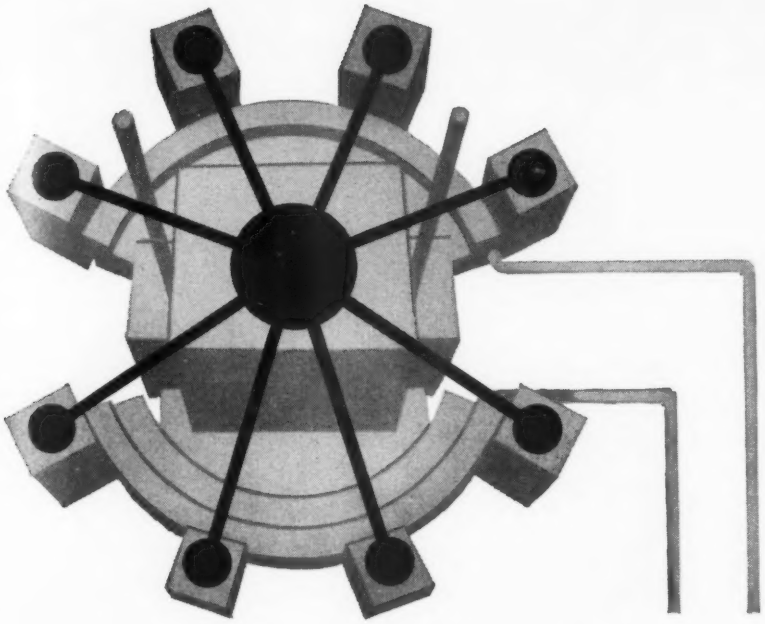
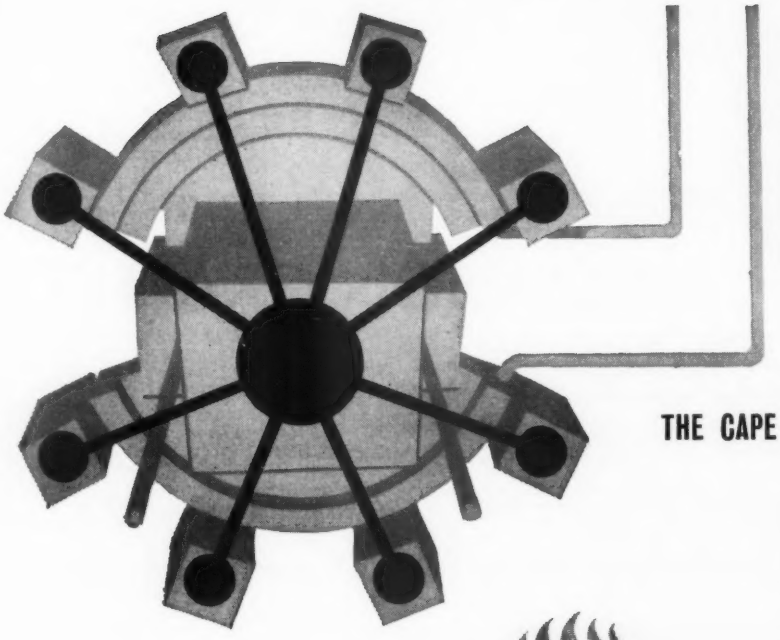


BERKELEY—a challenge to insulation



The heat developed by the twin reactors of the new Berkeley atomic power station poses problems of thermal insulation which will require new techniques in their solution. Confining and controlling such intense yet precious thermal energy constitutes a challenge—a test worthy of the knowledge and skill acquired in 65 years' experience of thermal insulation manufacture by The Cape Asbestos Company, to whom the contract has been entrusted.

THE CAPE ASBESTOS COMPANY LIMITED

Manufacturers of:

CAPOSITE
Moulded Amosite Asbestos Insulation

ROCKSIL
Rock Wool Insulation

PLUTO
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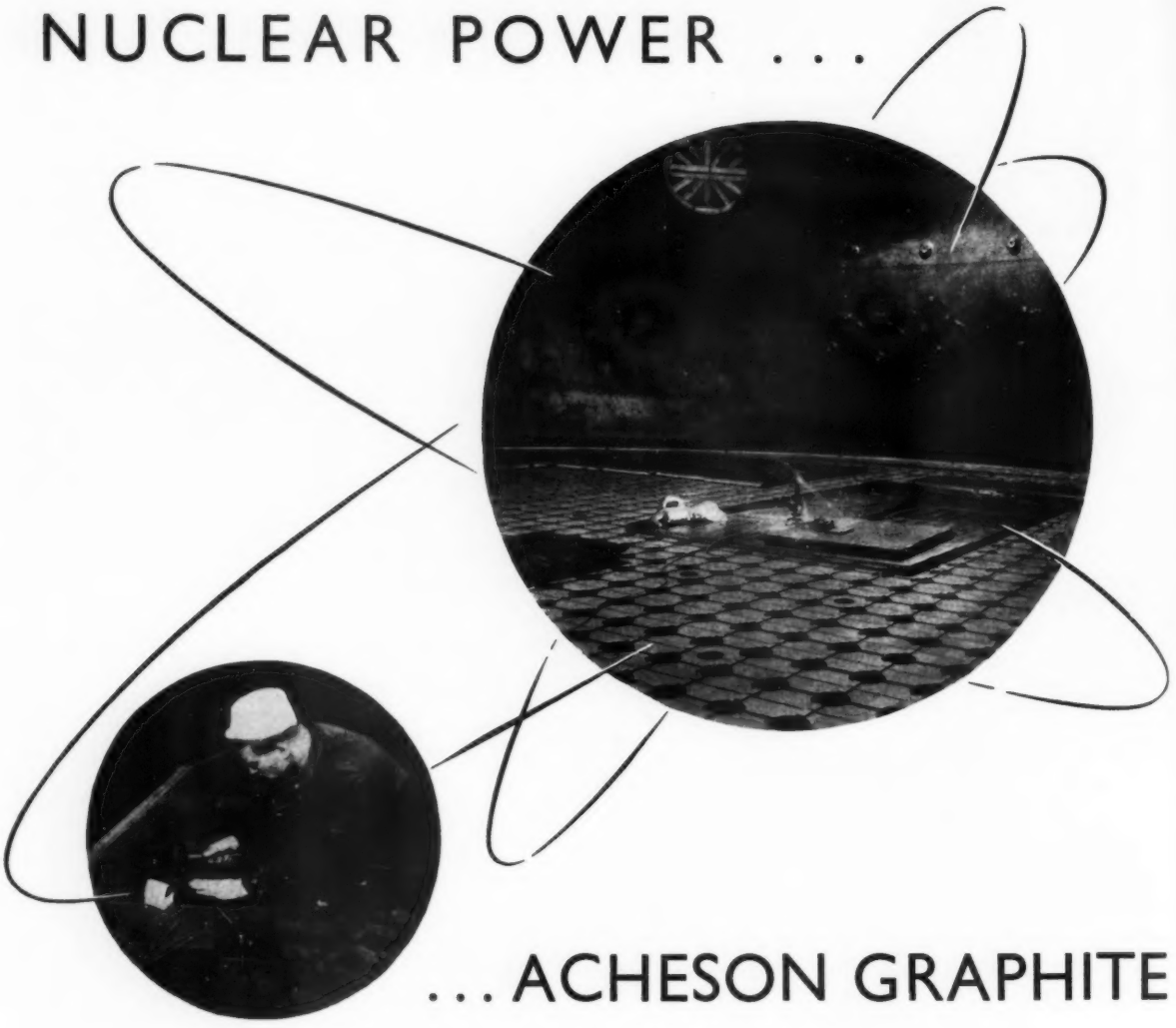
NUCLEAR POWER . . .



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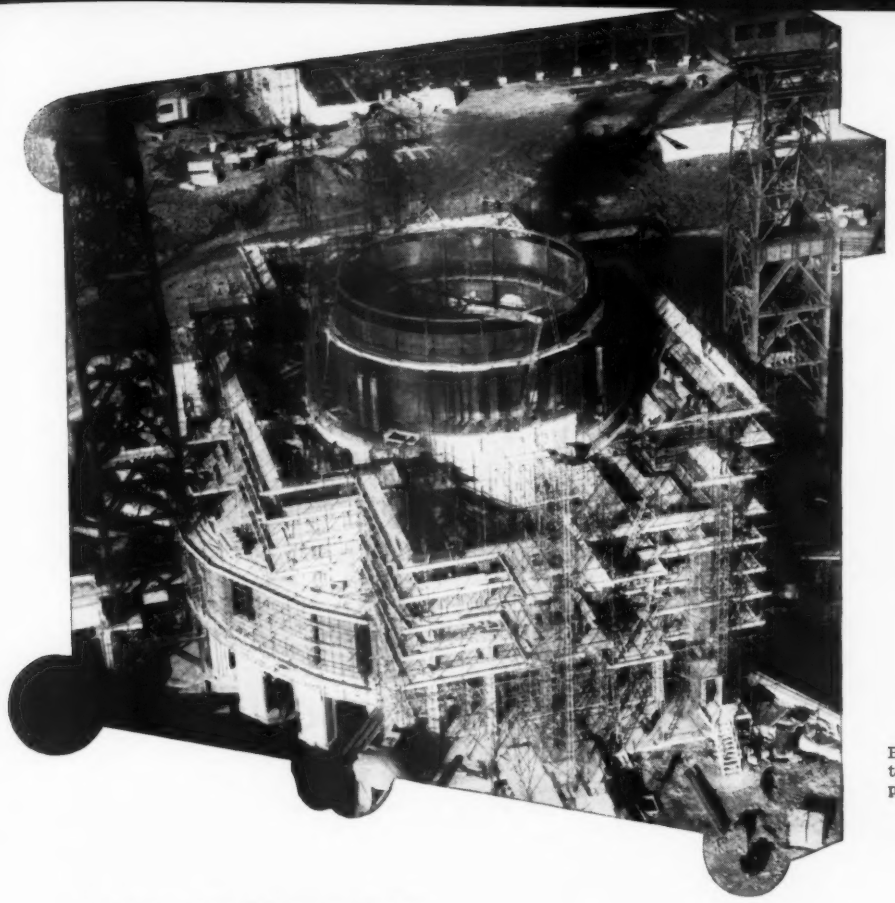

Berkeley No. 1 reactor; the thermal shield in process of construction.

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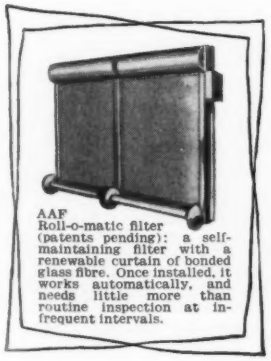

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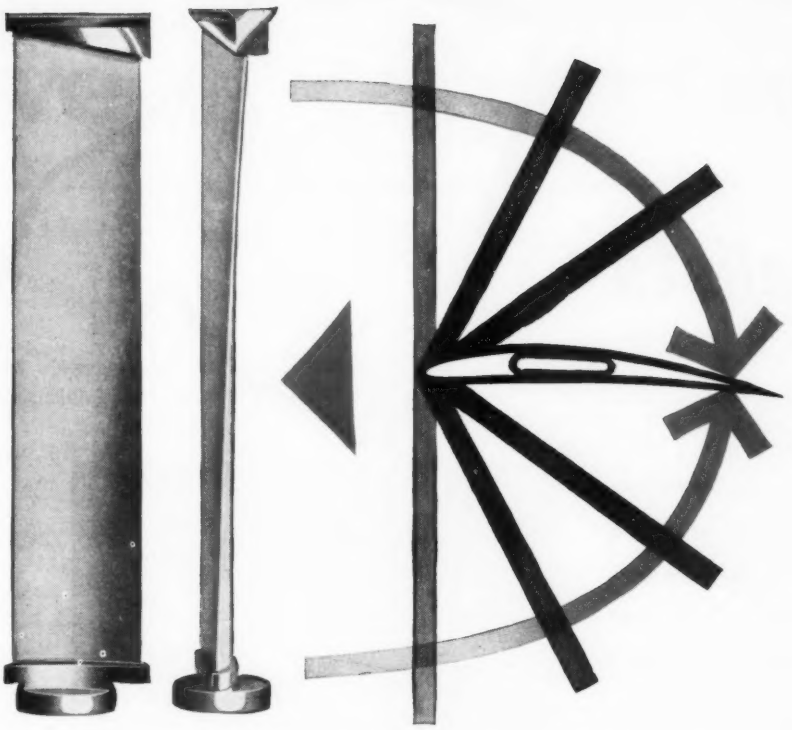

The illustration is shown by courtesy of Armstrong Siddeley Motors Ltd.

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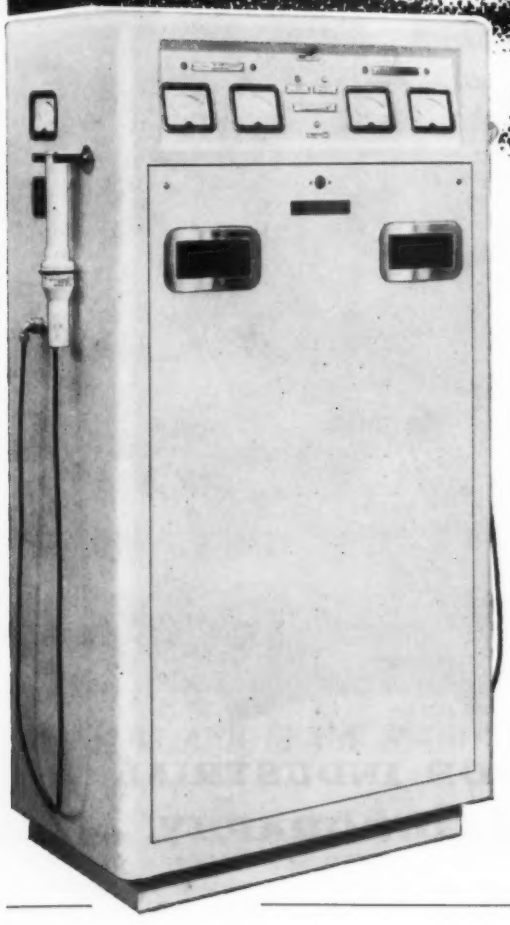

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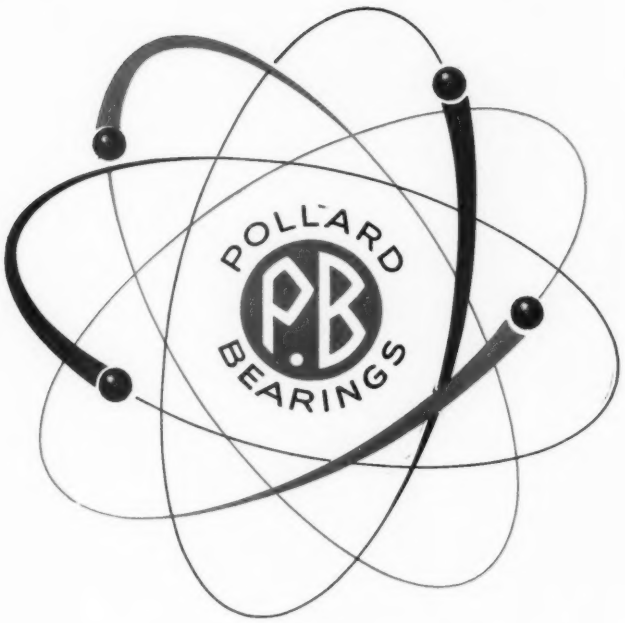

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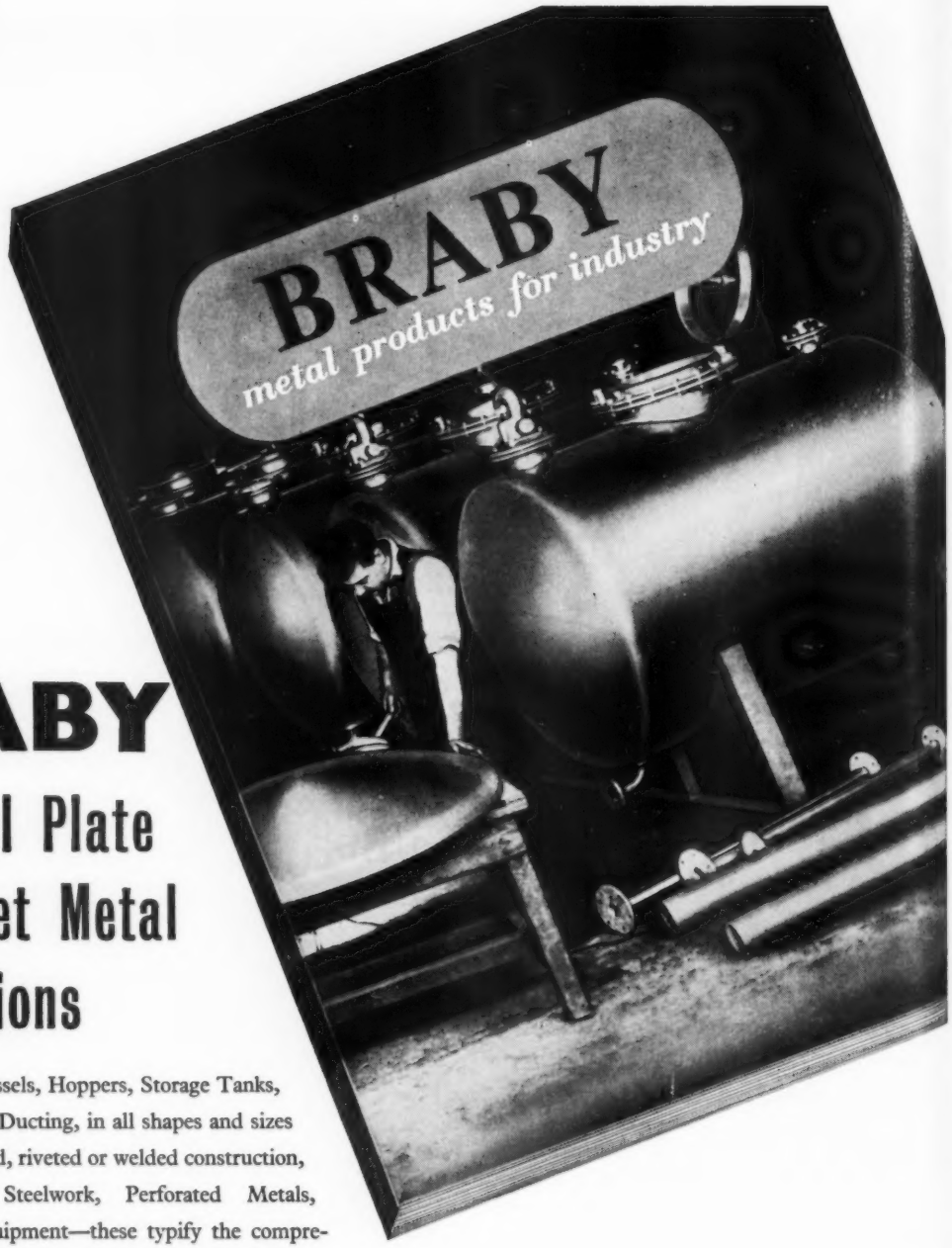

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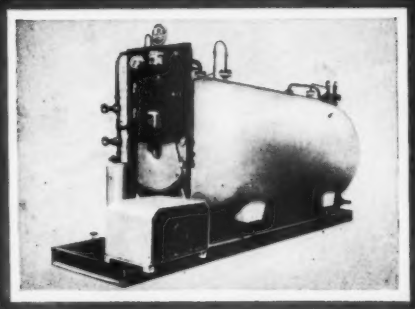

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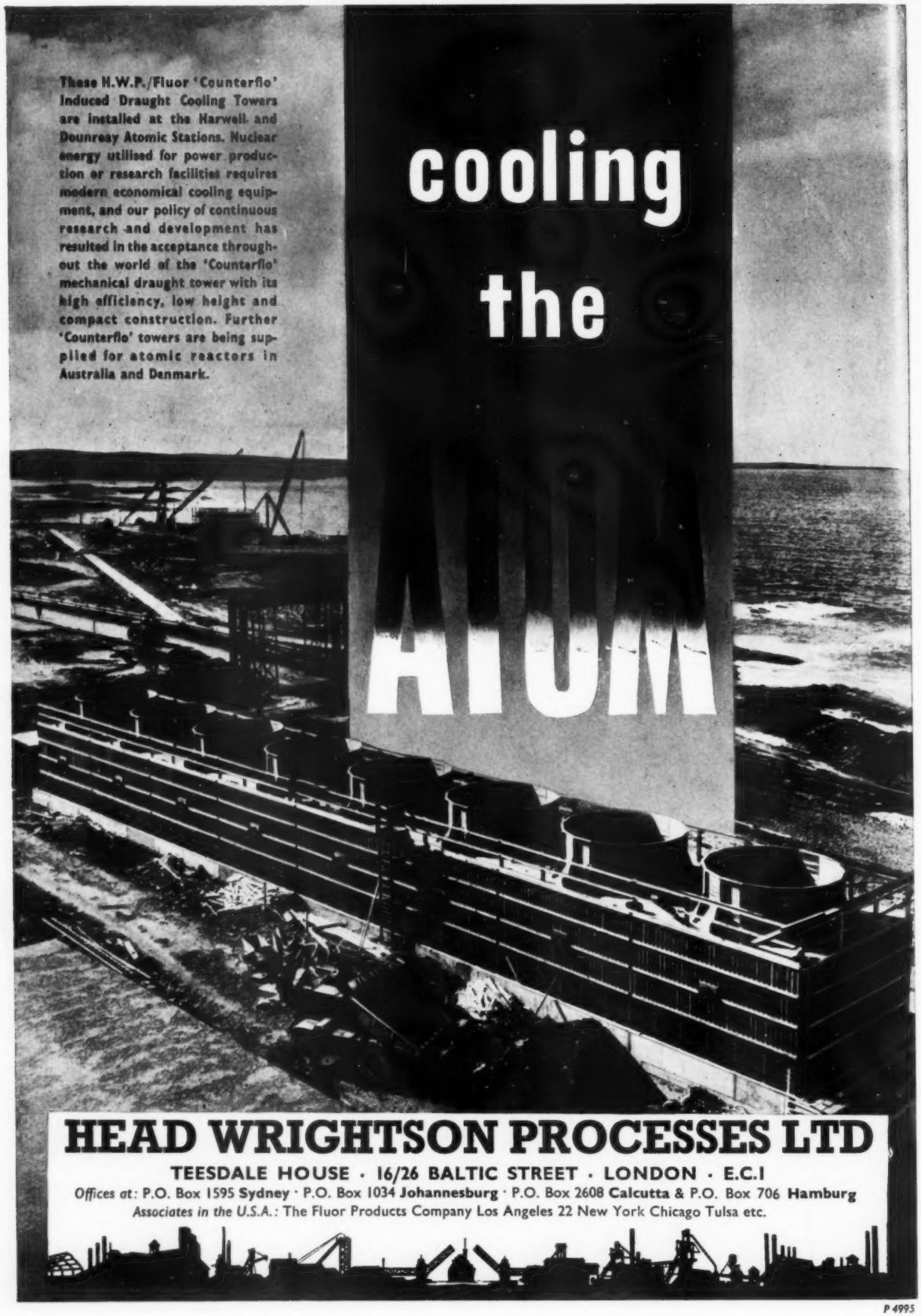
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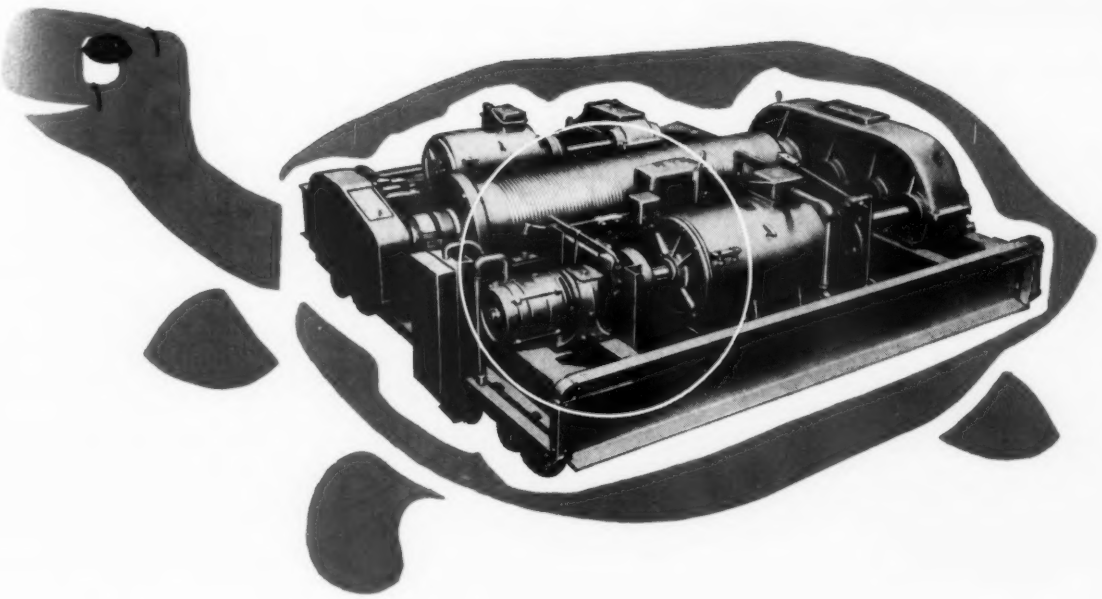

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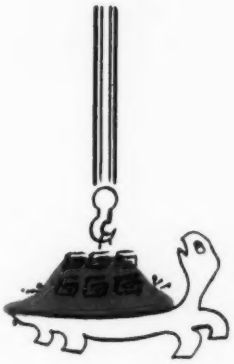

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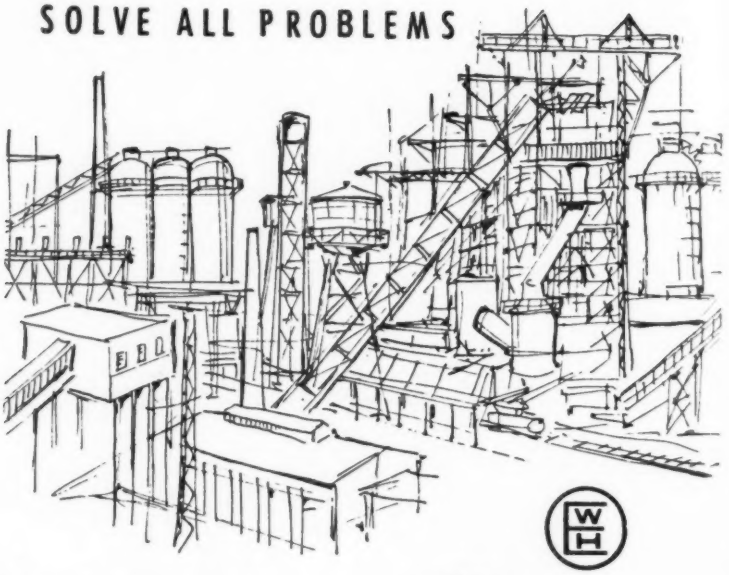

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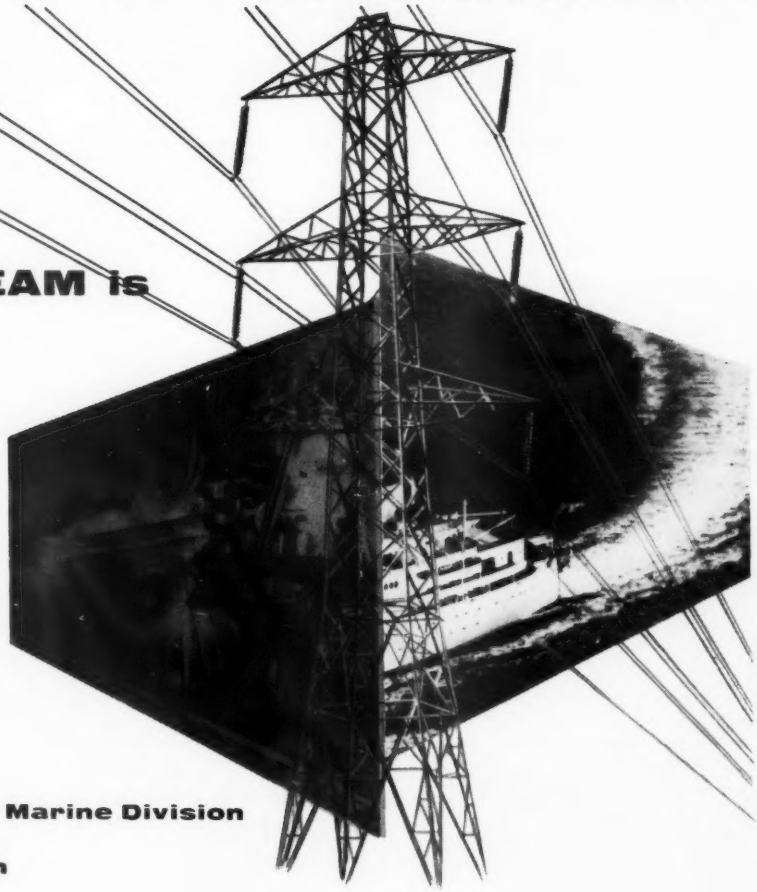

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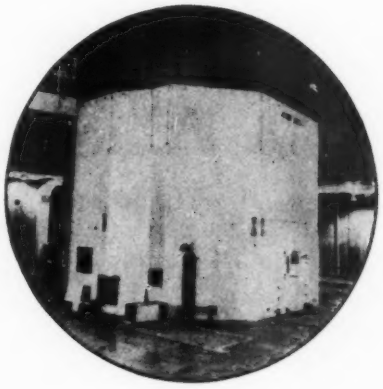

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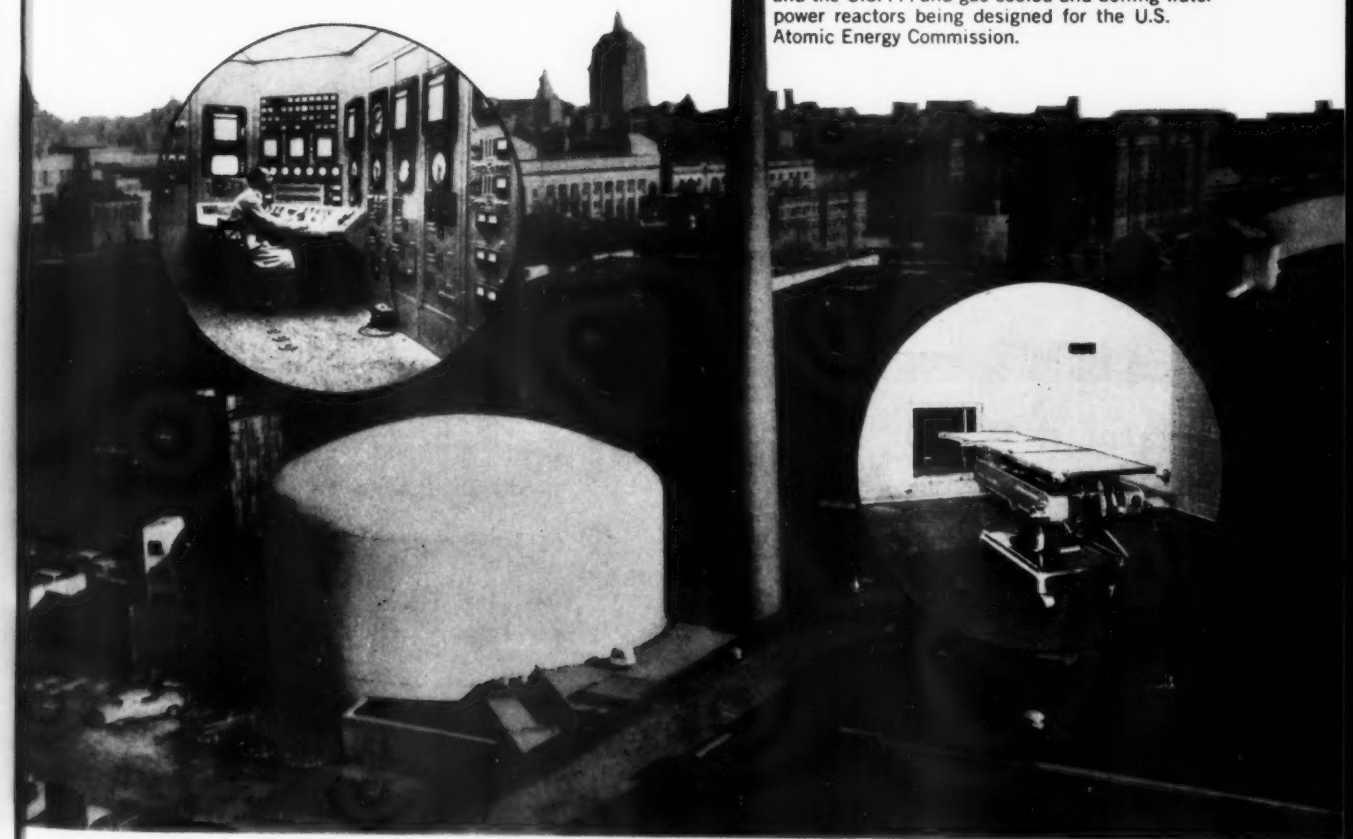

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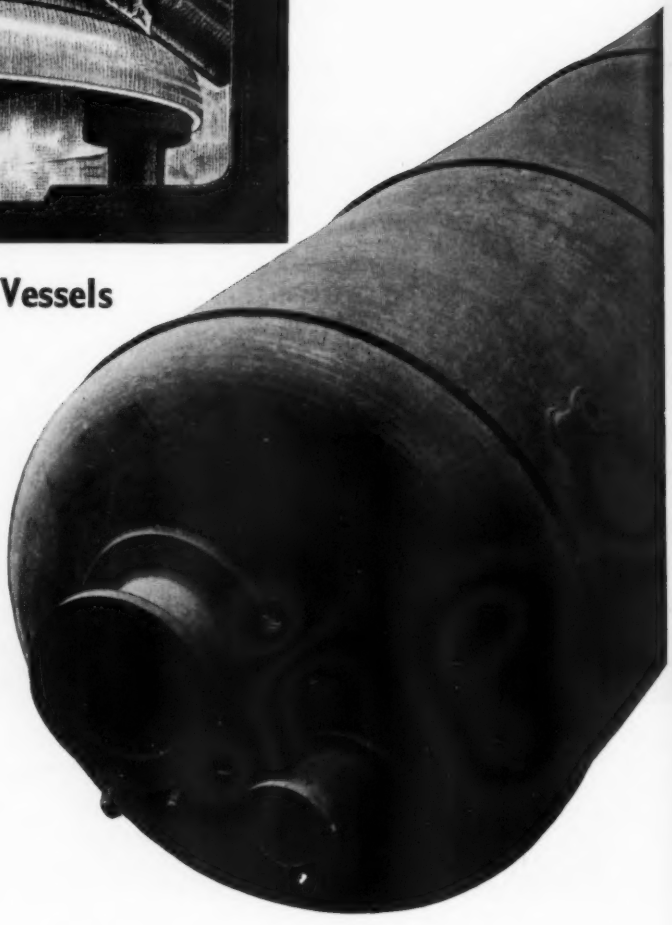

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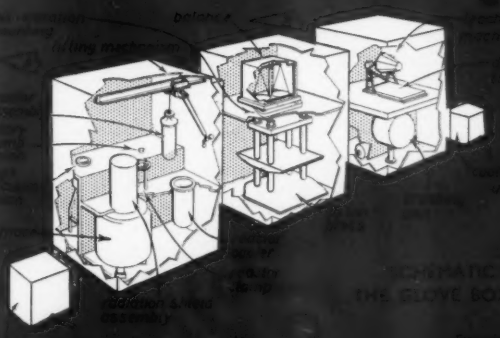

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Es ist oft schwierig für Inserenten alle technischen Einzelheiten über ihre Produkte in einem begrenzten Platz zu bringen. Sollten Sie noch weitere Auskünfte wünschen, streichen Sie einfach die bestimmten Nummern auf der nebenstehenden Karte an, und senden Sie sie an NUCLEAR POWER.

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E' talvolta difficile all'inserzionista di indicare in uno spazio ristretto tutti i particolari dei suoi prodotti. Qualora desideraste ricevere più ampie informazioni a questo riguardo, favorite segnare il numero appropriato sul cartellino qui accanto ed inviare quest'ultimo a NUCLEAR POWER.

SERVICIO DE INFORMACIÓN PARA EL LECTOR

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讀者詢問服務

在廣告上以有限的地方來解釋一些專門技術 及它們的功能 的確是有受限制的困难者倘若欲要知道一些詳細的情形就請將对頁的表格 取一張下來將閣下有疑问的項目 问笔勾一了都寄給予能工程总部可.

讀者サービス

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Nuclear Power
THE JOURNAL OF BRITISH NUCLEAR ENGINEERING

1	26	51	76	101	126	151	176	201
2	27	52	77	102	127	152	177	202
3	28	53	79	103	128	153	178	203
4	29	54	79	104	129	154	179	204
5	30	55	80	105	130	155	180	205
6	31	56	81	106	131	156	181	206
7	32	57	82	107	132	157	182	207
8	33	58	83	108	133	158	183	208
9	34	59	84	109	134	159	184	209
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11	36	61	86	111	136	161	186	211
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17	42	67	92	117	142	167	192	217
18	43	68	93	118	143	168	193	218
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20	45	70	95	120	145	170	195	220
21	46	71	96	121	146	171	196	221
22	47	72	97	122	147	172	197	222
23	48	73	98	123	148	173	198	223
24	49	74	99	124	149	174	199	224
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23	48	73	98	123	148	173	198	223
24	49	74	99	124	149	174	199	224
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October 1958

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S&L

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STEEL TUBES AND MANIPULATED PIPEWORK FOR NUCLEAR POWER STATIONS

Stewarts and Lloyds have already contributed substantially to the construction of Britain's new nuclear power stations, in which large quantities of steel tubes and manipulated pipework are required.

Contracts in hand include material to be supplied to all nuclear power stations now under construction.

Stewarts and Lloyds design, manufacture and install pipework for all types of industrial plants.

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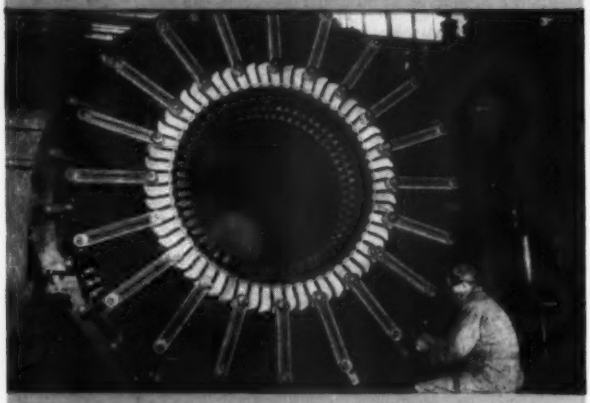
BEHIND THE SCENES

M & I ELECTRICAL INSULATING MATERIALS



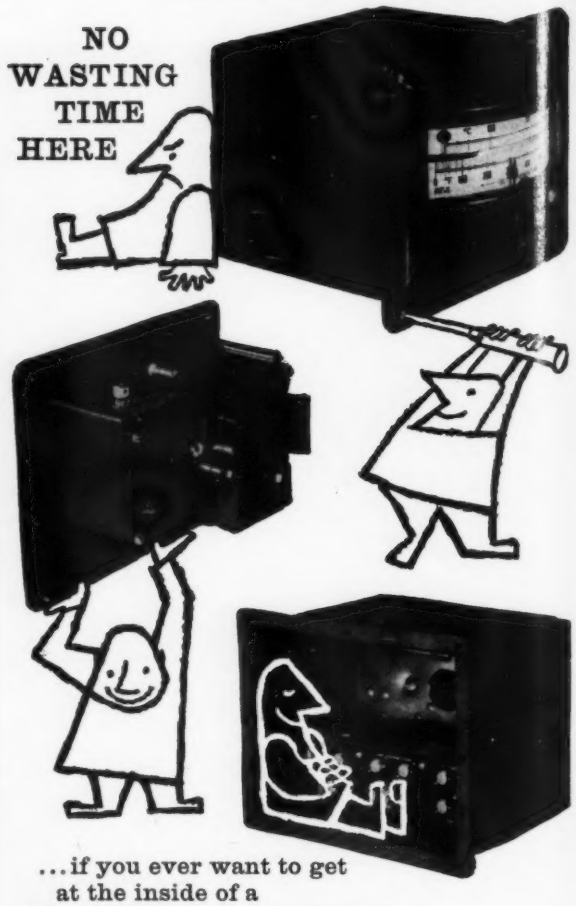
Photographs:—(top) by courtesy of the U.K. Atomic Energy Authority. (lower) by courtesy of C. A. Parsons & Co., Ltd.

"PAXOLIN" and "MICANITE" are in use in the 23 MW air cooled turbo-generators at Chapel Cross Nuclear Power Station—another example of our service to the electrical industry.

m and i — the electrical insulation people

THE MICANITE & INSULATORS CO., LTD.,
Blackhorse Lane, Walthamstow, London, E.17
Tel: Larkswood 5500. Grams: "Mytilite", Easphone, London
"PAXOLIN" is a registered trade mark

A50



...if you ever want to get at the inside of a West Temperature Controller, it opens from the front . . . comes out in sections . . .

1,2,3..SIMPLE

West Instruments are models of simplicity. They've brought the principles of temperature control to a fine technical art . . . stability allied to constant accuracy. Of course, West's specialise in temperature controllers; about the biggest sales in U.S.A.

What about after-sales service?

No wasting time there. Just as they do from all the major American and Continental cities, West's operate an organised system of regular calls throughout the country, to see that your temperature controller is always doing *precisely* what it was designed to do.

MODEL JP GARDSMAN

All components under-run for reliability. Corrects for thermal inertia, does not overshoot control points — unaffected by ambient temperatures — control unit simply unplugs for service or replacement.

WEST Instrument LIMITED

To: West Instruments Ltd., 52 Regent Street, Brighton 1
Please ask your area representative to let me have full details of the West Instrument Controllers.

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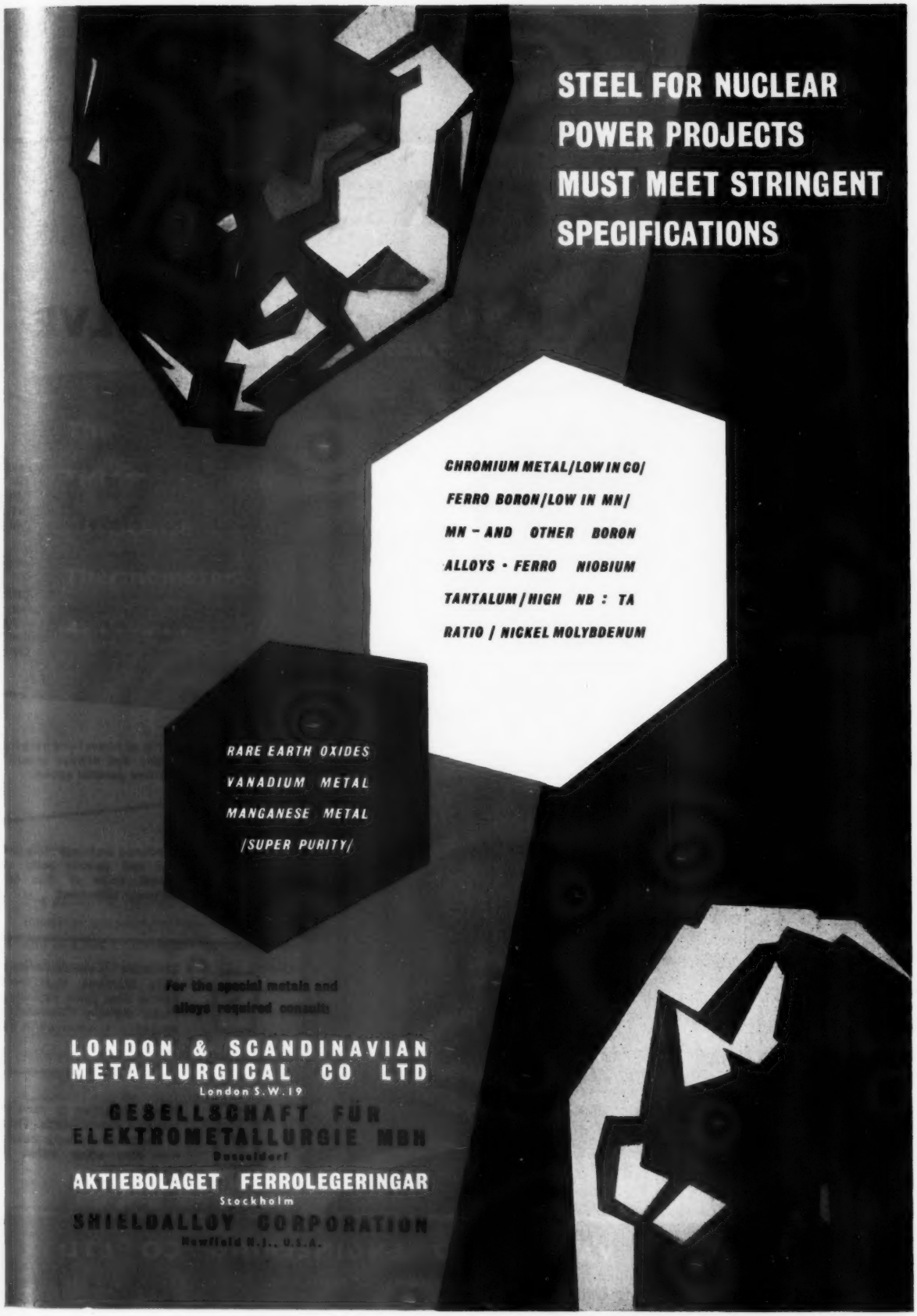
NP/10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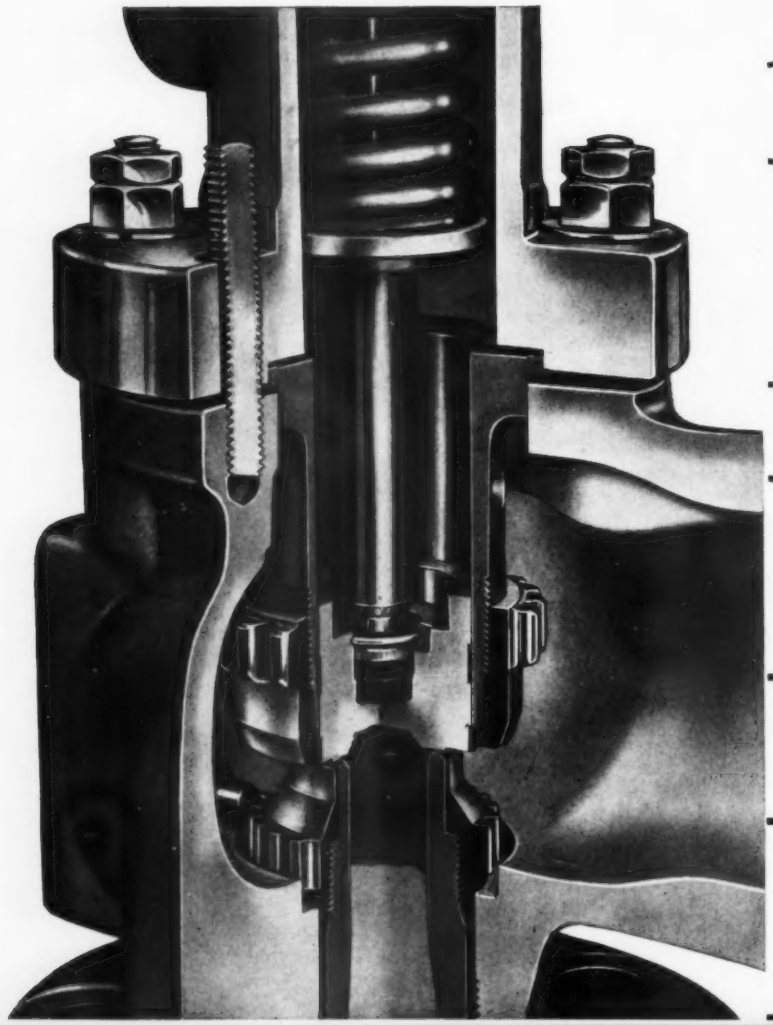
TYPE JO-35



1. Flat seats on both nozzle and disc lapped to optical flatness ensure bubble tight shut-off and facilitate maintenance when required.

2. Adjusting rings on both nozzle and guide ensure positive opening and closing and give optimum control over lift and maintain blow down to within 3 to 5%.

3. Fully circumferentially guided disc always ensures positive parallel action.

4. Hardened stainless steel pad and ball spindle point at lowest point of disc for accurate alignment.

5. Standard materials — steel body, stainless steel trim: nozzle, disc, guide, adjusting rings, spindle. Alternative materials available as specified.

6. Inlet connection to valve is made on nozzle flange. Fluid in contact only with nozzle and disc when valve is closed.

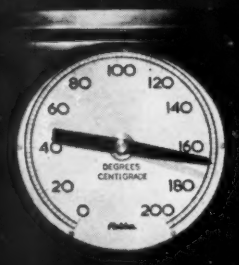
THE CROSBY VALVE AND ENGINEERING CO LTD

CROSBY WORKS, EALING ROAD, WEMBLEY, MIDDLESEX, ENGLAND. TELE: ALPERTON 2311

CHWR/10

1

A Multi-point Indicator



Any of these indicators can be provided with a multi-way switch enabling the temperature at any one of a number of points to be examined as required. Standard switches for multi-point are supplied with up to twenty ways so that twenty temperatures can be checked with one instrument.

A Pneumatic Controller

Available with simple proportional control only or with proportional plus integral control as required. Complete schemes including control valves can be supplied and commissioned.

The Fielden Resistance Thermometer as . . . . . .

For indicating, recording and controlling industrial temperatures between minus 200°C and plus 500°C, the versatile Fielden Resistance Thermometer offers an outstanding performance—at a very low capital cost. It is a Self Balancing instrument, of simple design, giving greater long term accuracy and reliability, with fewer maintenance and spares problems. Reduced thermal lag in the resistance bulb itself and electrical transmission ensures rapid response and gives better control.

This 22 page booklet containing technical details will be sent on request. Ask for Publication No. 209/FE.

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Level indication control
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Temperature indication, recording control.

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R.T.1

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Darlington 85% magnesia keeps that heat where it is useful

Is the precious heat used in your plant leaking away through badly insulated pipes and furnaces —heat that now costs you more than ever before? Keep the air temperature down and the working temperature up by applying Darlington 85% Magnesia insulation; keep that heat just where it should be—working for you, not against you. Many British power stations, including the new atomic power station at Calder Hall, owe their high thermal efficiency to Darlington Insulation materials and engineering. If you have insulation problems contact our technical department first, they will give you as much help and advice as you need.

The Chemical and Insulating Co. Ltd

DARLINGTON, CO. DURHAM

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...in electronic
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Coatings or films formed with this versatile product are, for practical purposes, chemically and physically inert; they can be used in close proximity to radio-active material and are transparent to radio-active emanations. The many applications for 'dag' colloidal graphite include the lubrication of reactor control mechanisms, louvres and sliding surfaces; the treatment of screw threads to prevent seizure, dry film and high temperature lubrication for I/c engines, air compressors, pumps, reduction gears, and for ball roller or plain bearings under conditions of high load, stress or speed

An Acheson service engineer will be pleased to call on you, or technical leaflets will be sent on request.

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Publishers Column

Intellectual marathon

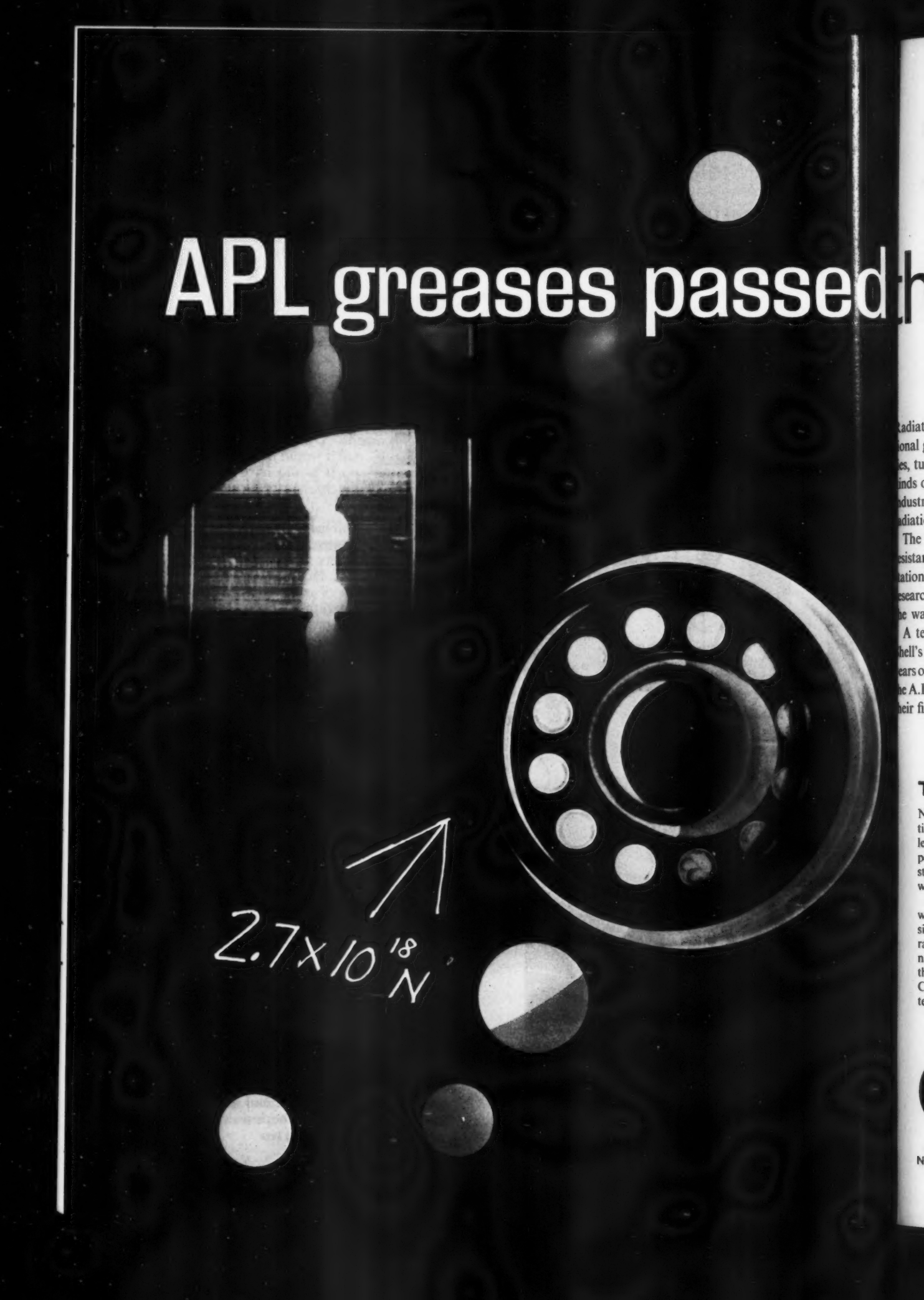
This has probably been the hardest-ever NUCLEAR POWER to produce although the Editorial Department say this regularly every month as the final pages are passed for press. To begin with, the United Nations inconsiderately arranged their 2nd Geneva Conference without any reference to us and we must say they couldn't have picked a more unfortunate fortnight as far as we're concerned! A fortnight earlier—or even a week—and it would have been easy; a week later and it would have been impossible to do much about the conference in this issue.

However, our publication date being 12 days after the close of the Conference, we believed our readers would be interested to know—and in fact have a right to know—something of what went on during this intellectual marathon. Thus we had to make some very special arrangements to cover it.

First we divided up the agenda into sections which we thought would be of most immediate interest to most of our readers and commissioned a team of experts to write special reports on these aspects. Their job was very difficult as, owing to the short time available, they had to obtain in advance such papers as were available in England and do most of their writing before they left for Geneva. Many papers were only available at the Conference and to take them into account meant hurried writing between sessions and a rush to catch the post back to London where our sub-editors were waiting to fit these odd bits into already-written articles. Some contributions were even taken down on tape which was then transcribed and edited.

The result of all this furious activity can be seen in the pages that follow. We're making no excuses but it should be realized that even with all the time in the world the physical limitations of a single issue of a magazine can do little with a two week conference of 2500 papers beyond highlighting the more important or spectacular developments, indicating trends of progress and giving the general flavour of the proceedings. This we hope we've done.

APL greases passed th



dheir finals in June...

adiation broke up the gel structure of conven-onal greases. They lost their lubricating proper-es, turned fluid or granulated. Completely new inds of greases were needed by the atomic power ndustry for the bearings situated within the adiation field.

The Shell Group started working out radiation-esistant APL greases whilst most nuclear power tations were still on the drawing-board, and the esearch that went into them is characteristic of he way Shell set about doing things.

A team of research workers was assembled at hell's Research Centre at Thornton. After four ears of research and testing – both at Thornton and he A.E.R.E. Harwell – APL greases were ready for heir finals. A sample was packed into a bearing and sunk into the B.E.P.O. pile. There it was not only subjected to mechanical working and high temperatures in CO_2, but also to an integrated pile dosage of 2.7×10^{18} thermal N. per sq. cm. plus associated radiation. APL greases sailed through their finals – and Shell are proud of it. They should be. For with these greases, Shell completed Britain's first range of Atomic Power Lubricants.

The moral of the APL story is that Shell research is supremely applicational. The Centre at Thornton is always ready to work with even the most specialised sectors of industry to produce the right lubricant for the job. If you and your organisation have any major lubrication problem, it will pay you to get in touch with your local distributor of Shell Industrial Lubricants.

The Research Story

Naturally a whole variety of greases were investigated. Conventional metallic soap greases were affected even by relatively low levels of radiation. Other greases based on synthetic and non-petroleum materials were examined and found to be equally unstable. Some of them softened appreciably and became tacky, whilst others hardened.

The Shell APL 700 series of greases are specially processed with an inorganic gelling agent, the base lubricant used being similar to the APL oils previously proved highly resistant to radiation. There were three series of tests. First tests were preliminary radiation tests at Harwell. Then the greases were tested for their lubricating qualities in a high temperature (400°F) pressurised CO_2 anti-friction bearing rig turning at 1,500 r.p.m. For the final tests in June, actual working conditions were simulated at Harwell.

SHELL

ATOMIC POWER LUBRICANTS

another proof of Shell leadership in lubrication

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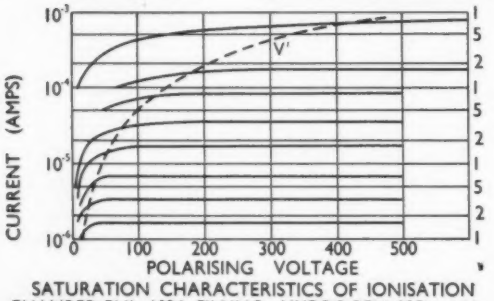
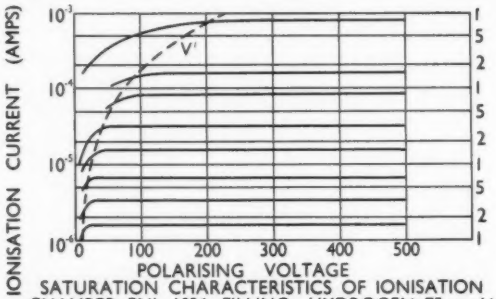
1025

NEUTRON DETECTORS FOR REACTOR CONTROL



SATURATION CHARACTERISTICS OF IONISATION CHAMBER PNI. 1026 FILLING: HYDROGEN 225 cm Hg



SATURATION CHARACTERISTICS OF IONISATION CHAMBER PNI. 1026 FILLING HYDROGEN 75 cm Hg

These two new units which have been specially designed for operation at high temperatures are now readily available. Designers and Engineers desiring further information should write for Data Sheet No. PNL 101.

OTHER PLESSEY NUCLEONICS ACTIVITIES INCLUDE:
Burst Fuel element detectors, flux scanning systems, health instrumentation including reactor effluent monitoring systems, pulse amplifiers, DC amplifiers, ratemeters, reactivity meters, installed test equipment and power units.

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Ilford, Essex, England

Type PNI
1026

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PNL4

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Packaged reactors wanted here

SIR: Just lately every issue of your excellent publication seems to have news and sometimes pictures of research reactors being ordered or going into operation in countries all over the world. However nearly all of these seem to be American and I wonder if British manufacturers are sufficiently alive to the very great possibilities in this direction.

I know that two British companies have had considerable success in this field but both the MERLIN and the DIDO tribe of reactors are enormously expensive and sophisticated appliances that are within the reach only of Government agencies or very wealthy foundations. The success of the American manufacturers in marketing and selling simple and *safe* zero-energy reactors suitable for universities and technical institutions has shown I believe without question that a considerable and widespread demand exists.

In the quite near future, no university engineering laboratory will be complete without a simple reactor on which the elements of operation and control can be demonstrated. They will in my opinion be eventually just as important as the boiler, diesel engine or wind-tunnel have been up till now.

Southampton S. H. BRIGGS

▶ *We would certainly agree that there is a serious gap here. Several British firms are quite prepared to build a research reactor if required but this is in no way the same as having standardized, packaged units on the shelf. It has just been announced incidentally that the Hawker Siddeley group are to supply the Argonne* ARGONAUT *educational reactor built here under licence. This is certainly a step forward but it would be good to see a purely British model on the market. Ed.*

Check-up on radioactivity

SIR: I was astonished to read (*Worldview* Sept p 399) that in the United States, of organizations engaged with radioactive substances only 56 pc passed an inspection completely satisfactorily. Has any similar inspection been carried out in Britain and if so what was the result?

Karachi, Pakistan K. SHUJAUDDIN

▶ *Actually the picture is not quite as bad as we might have suggested in the short space we gave the story. Firstly, only 26 pc of all licensed users of radioactive materials were in fact inspected and of these 44 pc were guilty of some non-compliance with the law. The great majority of these infringements were however of a very minor and non-dangerous nature. As we reported, about 5 pc of the inspected sample revealed potential or actual radiation hazard but even among these many cases were of relatively minor deviations.*

In Britain things are very different since in the first place one does not need a licence or permission to possess radioactive substances. Thus it is virtually impossible to know who has them. Control of such materials is in theory regulated by the Radioactive Substances Act 1948 but so far no actual regulations have been made under this Act. Industrial users of course come under the various Factories Acts and in the event of an escape of radioactivity actions could

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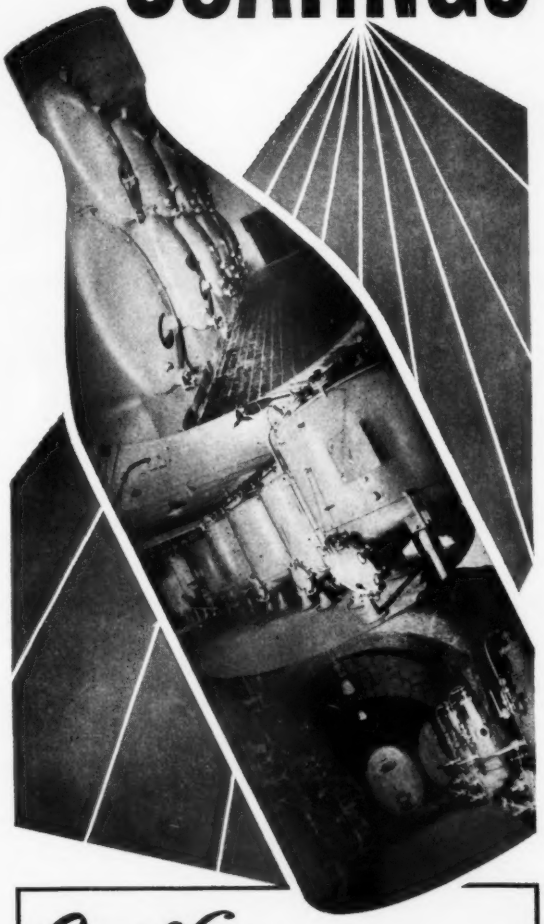
REACTION COATINGS



Specify—

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REACTION COATING SYSTEMS

for Storage Tanks
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THE CORROSION SPECIALISTS
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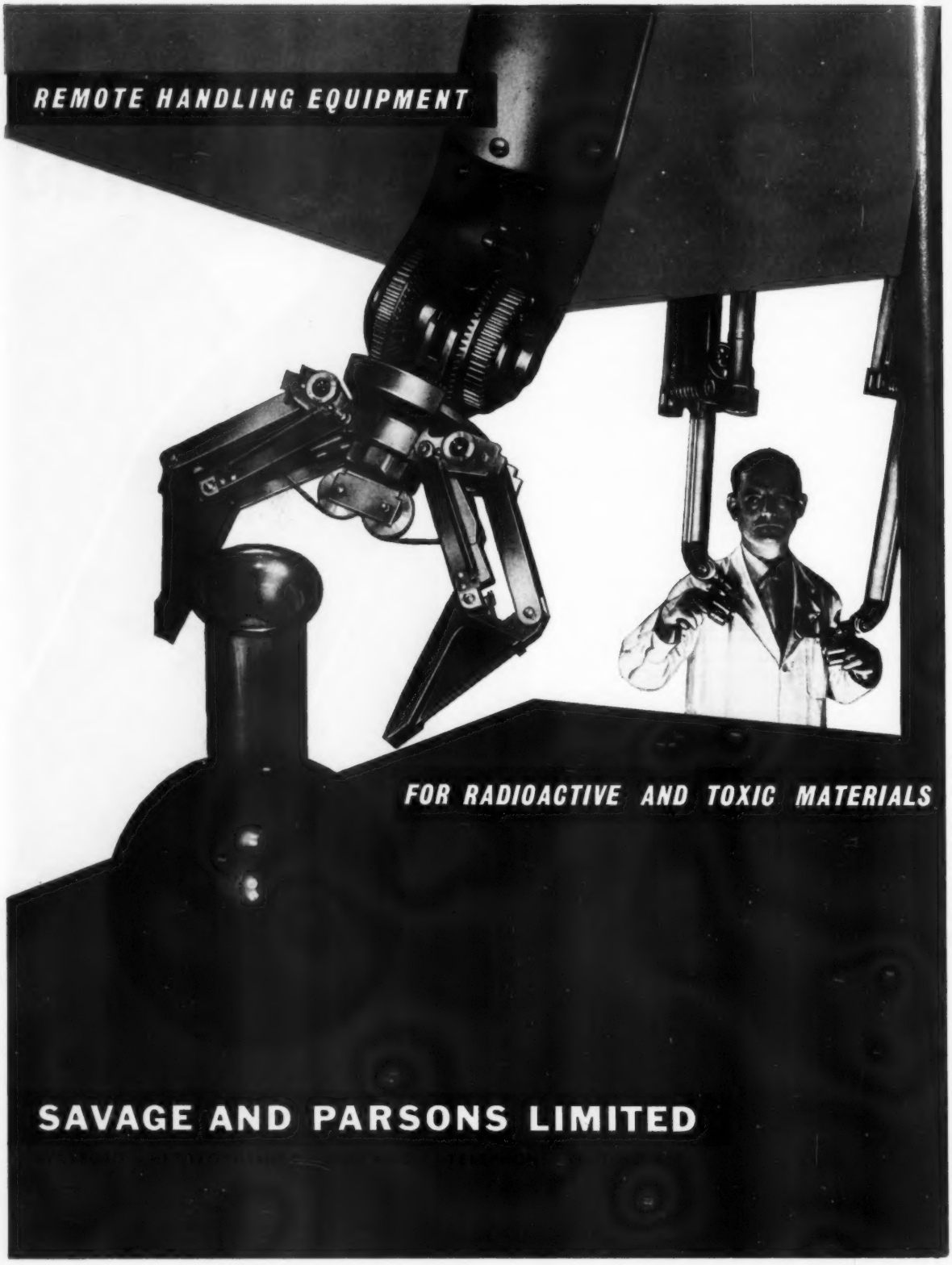
KELVIN WAY, CRAWLEY, SUSSEX. Tel. Crawley 1571 (3 lines)


REMOTE HANDLING EQUIPMENT
FOR RADIOACTIVE AND TOXIC MATERIALS
SAVAGE AND PARSONS LIMITED

SIR!

be brought under the Common Law. There is a Ministry of Health Code of Practice for use in hospitals etc and transport of isotopes is governed by regulations framed by the various organizations. Advice on these matters is given by the Radiological Protection Service but this is in no way a licensing body in the way the US Atomic Energy Commission is. Ed.

Radiation antidote

SIR: Last month you published a short news item about some kind of injection developed as a radiation antidote by the Argonne National Laboratory in the United States. Could you please supply me with some more details.

Berlin-Charlottenburg PAUL WOLF

▶ *The treatment was reported to the International Congress of Radiation Research on August 12 by Dr H. H. Vogel and D. L. Jordan of Argonne's Biological and Medical Research Division. Both streptomycin and bone marrow injections were given to neutron-irradiated mice and after 30 days less than 15 pc had died compared with 90-100 pc in a control group. Another radiation antidote reported at the same congress, by Dr D. G. Doherty of the Oak Ridge National Laboratory, is a compound known as S2-aminoethylisothiuronium bromide hydrobromide (AET). Extrapolating from animal results Doherty estimates that one gram of AET could reduce radiation damage to the human blood system from a 400 röntgen dose to about half. Such a dose could be expected to result in death within 30 days to about 50 pc of the subjects affected. Ed.*

Let Geneva flourish

SIR: Your correspondent J. K. Rosenberg (*Sir!* Sept p A65) who is so anxious to abolish the Geneva Conference can obviously never have attended one. I admit and agree with him that any given participant will be interested only in a certain proportion of the papers but I would not put it as low as 10 pc as he does. Owing to the system of parallel sessions this particular person need never be bored and will always have something to interest him.

I personally find these Geneva Conferences a source of inspiration and I think most people who attend would agree on the value of the informal meetings and discussions that abound.

There might be a case for more frequent—and shorter—conferences since three years' work poured out in two weeks is rather a lot, but I think that if this course were adopted the Conference would cease to attract the calibre of paper that it does under the present system.

Therefore I say let Geneva flourish and let us take our medicine in large, but not too frequent doses.

London MESON

▶ *This controversial question is reviewed in this month's leading article on p A63. Ed.*

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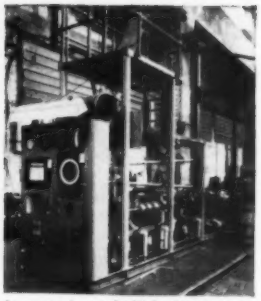

An experimental high temperature Aqueous Corrosion Loop built by Cravens Ltd. for the United Kingdom Atomic Energy Authority's establishment at Harwell.

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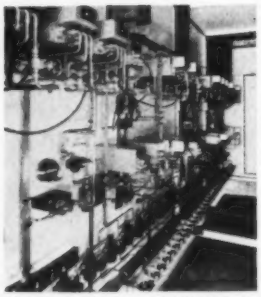
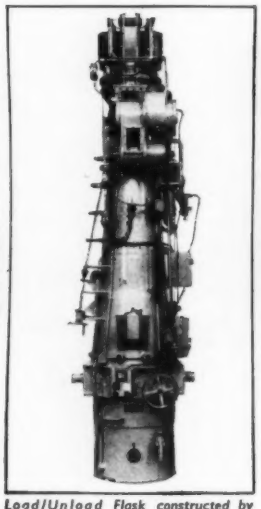


Control panel for a U.K.A.E.A. establishment.



Load/Unload Flask constructed by Cravens Ltd. Photo by courtesy of the Australian Atomic Energy Commission.

Thermo-couple shield plugs, for Nuclear reactors, being made at Cravens Ltd., Sheffield.

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Nuclear Power
THE JOURNAL OF BRITISH NUCLEAR ENGINEERING
OCTOBER 1958 VOLUME 3 NUMBER 30

A Plea for Devolution

Evaluated purely in terms of words, man-hours and money, the 1958 Geneva Conference certainly put the 1955 affair in the shade, but if it was altogether brighter, bigger and brasher it somehow never quite recaptured the spirit of the earlier conference. The main reason for this is of course not far to seek. Until September 1955 nearly everything in atomic energy was classified and on the sudden removal of much of the restrictions almost anything appeared to be startlingly novel or even sensational. Now we have become so pressurized by events and the sheer glamour of Geneva that a mere advance is not enough: we have to have breakthroughs or nothing. This is not good for science.

True enough, the standard of the papers was extraordinarily high but there was ample evidence to suggest that much of the work was not strictly new and had been 'saved up' for this important occasion. This not only made the Conference unbelievably cumbersome; it amounts to a new kind of classification which has already led to periodical 'rush hours' of information releases in which everyone gets in everyone else's way. What is obviously wanted is some kind of 'staggering' so that people can go about their business in an orderly way instead of being trampled underfoot.

Whether this scientific *triennale* is to remain with us as a permanent kind of intellectual Olympiad remains to be seen. Certainly President Eisenhower's idea has accomplished much already. Was it not the 1955 Geneva that declassified peaceful fission and 1958 that finally unshackled fusion? But having brought off these two feats would another conference on the same lines have anything further to achieve?

By all means let us have international conferences—they are invaluable for the personal contacts alone—but let them be more specialized now that atomic energy is out of its infancy. The obvious body to take over responsibility for this important work is the International Atomic Energy Agency and it ought straight away—during its Second General Conference—to get down to the idea of a whole series of sectional conferences on the many aspects involved.

Clearly the thing of the moment is thermonuclear and while the work is in its present very difficult phase a yearly conference would not be too frequent. This could be held in the various countries working on the problem and delegates would then be able to visit laboratories and see things for themselves instead of relying on rather doubtful models. For example next year a meeting could well be organized in the USA or the USSR—in both these countries important results should become available during the next six months or so.

Such a departure from the original Geneva idea is in fact already happening. Last year's Paris UNESCO conference largely 'scooped' the Geneva isotope sessions and this year there were comparatively few papers on instrumentation because of the Paris meeting of specialists which followed the next week.

Atoms for Peace was, and is, a noble idea and in putting forward this plea for devolution we are not in any way denigrating it. The whole field is however now so vast that, if only out of consideration for the citizens of Geneva and the staff of the United Nations, we should consider new and better ways of developing it.

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Worldview

the month in atomic energy

UK firm cuts heavy water costs

The announcement by Constructors-John Brown that they have developed a method of producing heavy water at £7·7/lb has excited considerable interest among countries who would like to be able to manufacture their own supplies. Hitherto the US, selling at £10/lb mainly as a result of large scale production, has made it uneconomic for anyone else to compete. Another consequence of a cheaper process could be to make the UK's proposed second string—the heavy water moderated gas-cooled reactor—more attractive. Studies have shown that even at the US price for heavy water this could produce power as cheaply as the graphite moderated type.

CJB's method, which uses extraction of heavy hydrogen from ammonia synthesis gas by ammonia exchange, has been known in broad principle for some time, but its research department has developed a new route and the company has come out with a more or less complete blueprint for a plant producing 28 tons a year as a by-product to a factory making nitrogen for fertilizers. Capital costs are given as about £80,000 per tonne of heavy water production a year, and about £2 per lb covers operating costs in most locations. With allowances for depreciation and interest on capital at the public utility level of 15 pc the heavy water could be sold at £7·7 a lb. This project would be linked with a factory producing about 160,000 tons a year of ammonia synthesis gas and a country starting from scratch and building both plants would have to lay out £M20–30.

The extraction of deuterium from ammonia synthesis gas and the first stage of concentration to 23 times natural would be accomplished by the ammonia-hydrogen exchange process. Further concentration by ammonia distillation follows and the deuterium is finally purified by distillation of water. According to CJB the heavy water plant could be operated by a staff of sixteen men and their design shows that it would cover an area of 60,000 sq ft.

Iron shot knocked out Calder set

The overspeeding and ultimate disintegration of the turboalternator in Calder Hall B station (*Worldview* August) was caused by fragments of chilled iron shot which found their way into the steam system; result was a coincident failure of two valves to function automatically. In their report the Board of Enquiry say they have been unable to ascertain 'fully' how shot came to be in the steam system but they feel 'bound to recommend' that extra precautions should be taken in future to ensure that hard materials—where these are known to be used—do not enter or remain in the system.

In a reconstruction of the accident the Board established that at approximately 7.40 in the evening the foreman in charge of reactor No 3, which was providing steam for No 5 turbogenerator, received indications on his reactor instruments which suggested that it might be desirable for the reactor to be shut down. At about 7.59 p.m. he warned the electrical control room that this might be necessary. At about 8.03 p.m., in accordance with his standing instructions, he shut the reactor down by pressing the shut-down button. He told the board that as the last control rod went home, he heard the noise of the turbogenerator disintegrating.

The Authority turbine driver's first knowledge that conditions were other than normal was when he heard the speed of the machine increase. He attempted to stop it by employing manual control but it became clear that the machine was overspeeding and beyond control. The set vibrated violently, flames came from the generator and it finally broke up.

Fusion: out in the open now

The day before the Geneva Conference opened officially Sir John Cockcroft and Lewis L. Strauss, former USAEC chairman and now special assistant to President Eisenhower on atomic affairs, announced that both countries had completely declassified their programme on controlled thermonuclear work.

The practical importance of this should not be overestimated, for workers in both countries have had full access to each other's findings since 1956. It will however be of great benefit to scientists in other countries, who will now be able to share in US/UK experience. Later, it was announced by Sir John that British thermonuclear work is to be transferred to the new Atomic Energy Establishment at Winfrith Heath, Dorset. This will however not take place until 1961–63 and it is unlikely that ZETA will be moved, for by then it is probable it will have been superseded by more advanced machines and largely outlived its usefulness. The ZETA-II machine, which is still on the drawing board, will however be built at Winfrith.

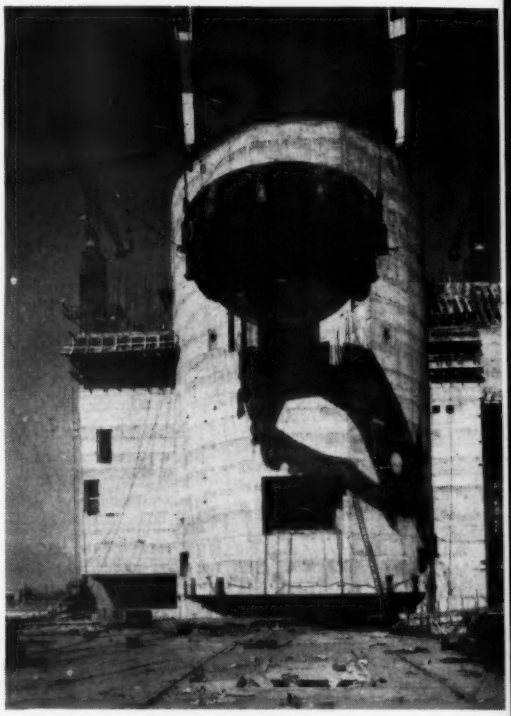
This move probably means that the aim is to make the Dorset centre a completely declassified establishment—which would of course ease administration.

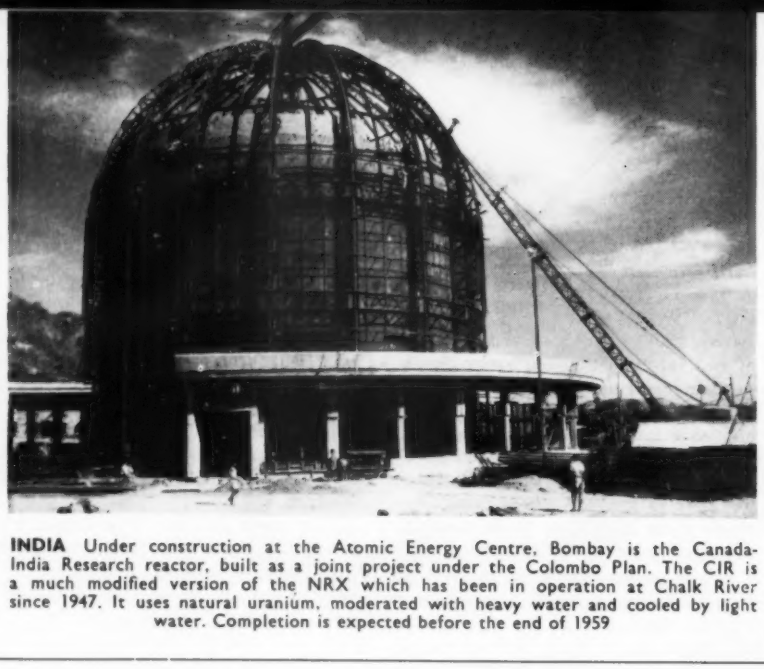
CUBA

UK-US team to build a power BWR

A nuclear power plant incorporating a 22 MWe boiling water reactor is to be built at Santa Lucia, west of Havana, by

FRANCE At the Chinon site of the first commercial power reactor, EDF-1, the bottom dome of the pressure vessel is hoisted up over the already complete biological shield. The heat exchanger block is behind in this view and the entire plant will later be enclosed in a spherical pressure shell. The turbine on the contrary will be completely in the open





INDIA Under construction at the Atomic Energy Centre, Bombay is the Canada-India Research reactor, built as a joint project under the Colombo Plan. The CIR is a much modified version of the NRX which has been in operation at Chalk River since 1947. It uses natural uranium, moderated with heavy water and cooled by light water. Completion is expected before the end of 1959

the international group Mitchell Engineering (UK)—American Machine and Foundry Company—General Nuclear Engineering of Florida. The reactor will be a dual cycle BWR with oil fired superheating, and Gordon Jackson, manager of Mitchell's nuclear department, disclosed to NUCLEAR POWER that they hope to start work on site in October. The British company will be responsible for most of the construction, excluding the core and control system. Fuel elements will be made by AMF.

The plant forms part of a £M5¼ electrification scheme by BANDES, the National Bank for Social and Economic Development, and an extensive investigation made by the Bank shows that not only will a nuclear reactor be suitable, but it will produce electricity more cheaply than conventional plant right away and bring down the prevailing power costs. The area has no natural energy sources and the lack of cheap power has held back exploitation of its mining and agricultural potentialities. Projects which will be aided by the new station include a sulphuric acid plant, expansion of copper mining and an ore smelting installation; to meet the demands of these construction of the nuclear plant must be finished by early 1961.

Cuba is the second country to buy an American type power reactor and the previous order—by Western Germany—was also for a BWR. The same group was strongly in the running for the contract, and actually received a letter of intent, but negotiations foundered on the question of guarantees for safe working; the German plant is now being supplied by the US General Electric Company, which unlike the AMF-Mitchell-GNE group has actually built a BWR—at Vallecitos. This has been working for some time. The group also missed out on the 22 MWe plant for the Elk River scheme in the US, and the Cuban reactor will be its first.

FRANCE

Going it alone on diffusion

A gaseous diffusion plant for separation of U-235 has now definitely been decided on and an initial budget appropriation of 25,000 million francs has been already allotted to get the work started. This was disclosed by the French delegation to the Geneva Conference which furthermore presented six papers on the subject. This action aroused some friction with the UK and US delegations and Sir John Cockcroft said he did not think the French should have made these disclosures.

As is well known, the Commissariat à l'Energie Atomique has been going it alone for some years on diffusion studies and it is now revealed that a private company, with the pleasantly vague title of Société de Recherches et Techniques Industrielles (SRTI) has been founded for developing the process on an industrial scale. By the beginning of 1957 work had got to the stage where a pilot plant could be planned and this is now under construction.

A great deal of work has been carried out on porous diaphragms and in particular aluminium, nickel and teflon has been studied. Pore dimensions must be of the order of 1/100 micron with a very high density of pores. The barrier must also be extremely thin—of the order of 1/10 mm and yet be able to withstand pressures of up to 1 atmosphere. Compressor design, too, has proved a most difficult problem.

Just why France is so anxious to build a diffusion plant is still not as clear as official statements would make out. The CEA say their U-235 is purely a supplementary activity—'a form of insurance'—to their main aim of plutonium utilization but they do not say to what degree of enrichment they are aiming at. If it turns out that full enrichment is the objective it can only be concluded that military thoughts are not entirely absent in this new development.

ITALY

CNRN takes a TRIGA

An above-ground version of US General Dynamic's TRIGA reactor, known as Mark II, is to be bought by the National Committee of Nuclear Research for its School of Applied Physics and Nuclear Engineering at Rome.

In a statement at the signing of the contract, Professor Ippolito, Secretary general of CNRN, said TRIGA was chosen after 'exhaustive' investigation and study of numerous other reactors on account of simplicity, versatility, and complete inherent safety. The reactor will be operated on a permanent basis at a power level of 30 kW with intermittent runs at 100 kW.

A TRIGA was one of the four working American reactors on show at Geneva. One of the others—an Aerojet-Nucleonics 201 reactor—has been bought by the Swiss National Fund for Scientific Research for installation in the University of Geneva's Institute of Physics. Fuelled with 20 pc enriched uranium dioxide dispersed in polythene and graphite moderated the reactor is now in mass production by Aerojet-Nucleonics at the rate of three a month.

RUSSIA

100 MWe reactor goes critical

Almost casually, the leader of the Russian delegation to Geneva, Professor Emelyanov, announced during the conference that the Russians were building a nuclear power station in Siberia and that one reactor—of 100 MWe capacity—had already gone critical on September 8. With five other identical reactors going up, the plant is the largest under construction in the world. His disclosure was followed by a film showing the station and the surrounding town, which though new and—Professor Emelyanov assured questioners—unnamed, is already a fair size. He would give no further details beyond the fact that the reactors use natural-U.

Another reactor which has recently gone into operation is the BR5, a 5 MWt experimental fast breeder which has been constructed on the site of the dis-

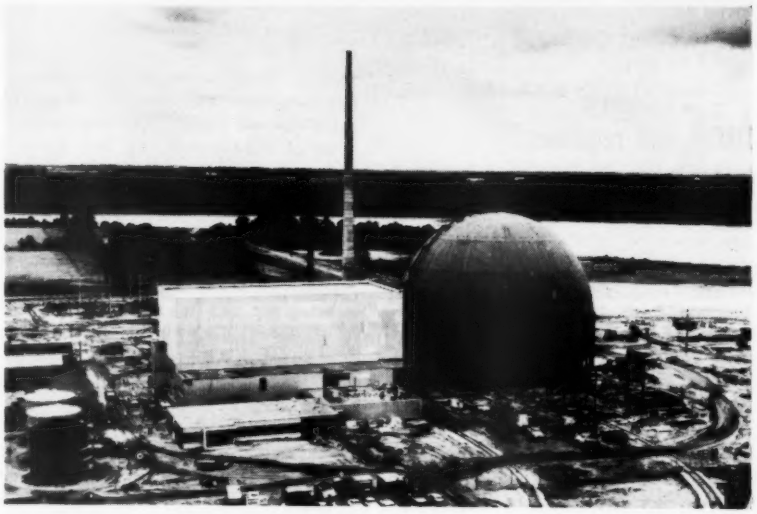
mantled 2 MWt BR2 at the Ulyanovsk centre on the Volga. Designed as a transition stage between the mercury cooled BR2 and the projected 50 MWt power plant the sodium-cooled BN50, it employs sodium at a maximum temperature of 500°C and has a neutron flux of 10^{15}. It will give the Russians a chance to get experience in working with a sodium coolant as well as offering facilities for testing of fuel elements etc for the BN50. In paper 2129 it was stated that the core of BR5 is fuelled with steel-canned sintered plutonium oxide elements contained in 80 hexagonal steel sub assemblies: total number of the 28 cm by 5 cm dia fuel elements in the core is 1520. Shielding and control of the reactor differs little from the BR2. It is not intended for electricity production and the two parallel cooling circuits take the heat to the surrounding air and to a condenser via an air exchanger and a boiler respectively.

SWEDEN

Nuclear plans slashed

The ADAM project for a 75 MW nuclear district heating plant at Vasteras has been abandoned and the proposed R-III—to be built in a new suburb of Stockholm by the State Power Board—is to be renamed R-III/ADAM. Both designs were for a natural uranium oxide pressurized heavy water reactor but R-III includes a back-pressure turbine for electricity production: output will be 15 MWe as well as 70 MW heat for about 12,000 suburban houses—though none will be permitted within 1 km of the reactor.

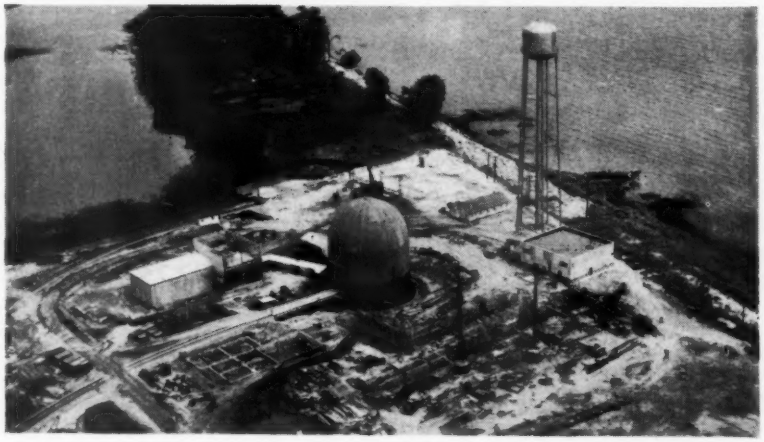
ADAM, intended to be the first of half a dozen reactors for district heating by 1965, was designed by ASEA, the big electro-mechanical group, under the supervision of the Atomic Energy Company. Though both ADAM and R-III are stepping-stones only, with no pretensions to being economic propositions, it is reported that the decision to drop ADAM results from a reappraisal which showed that costs—specially for the heavy water—would be greater than at first anticipated. At the same time, Sweden has a fairly urgent need for nuclear power. Gustav Cederwall, chairman of the Atomic Energy Board, said recently that a continuation of present trends in the energy supply position could lead to a grave situation for the country's balance of trade. It has no fossil fuels of its own and in spite of a large hydroelectricity scheme has to import over two thirds of its energy needs. For this reason the Government is anxious to make early use of the country's large uranium deposits and though ADAM has been dropped, the objective for a 100 MWe nuclear power



UNITED STATES Construction of Commonwealth Edison's 180 MW power station is six months ahead of schedule at Dresden, about 47 miles southwest of Chicago and it will be in operation by June 1960 (above). The boiling water reactor is contained in a 190 ft sphere, sunk 40 ft into the ground. Part of the steam is direct from the reactor and non-condensable gases are removed by an air ejector, filtered and sent to the 300 ft stack.

About 35 miles from Detroit, on Lake Michigan, the Enrico Fermi Fast breeder power reactor (centre) is coming along fast and initial criticality trials are due to start in September 1960. It is designed to produce 100 MWe for Detroit Edison's network but the turbine installed is a 156 MW set, indicating confidence that this output will be exceeded eventually.

Only 24 miles from New York City on the banks of the Hudson River Consolidated Edison's Indian Point station (bottom) is due operating late in 1960. It will have a Westinghouse pressurized water reactor using mixed fully-enriched urania and natural thoria, and by means of an oil-fired superheater the total output will be 275 MWe. View shows construction of biological shield and tunnel to the river



plant by 1965 after gaining experience with R-III/ADAM—due critical in 1960—is still on.

——UNITED STATES——

HRE-II runs regardless

Undeterred by the leak which developed between the reactor core and blanket region when it was first brought to design power of 5MWt (*Worldview* May), the operators of the homogeneous reactor No 2 have been running it since with fuel on both the core and blanket. Cause of the original leak has not been found, but Union Carbide, who operate the reactor for the AEC, are pleased with HRE-II's reliability under the new regime. During one trial it has produced over 1600 MW hours of heat at power levels up to 5 MW. At present about 3 MWt are produced in the core and 2 MWt in the blanket region; in the initial trial the figures were 5 MWt and 220 kWt respectively. Part of the heat is being used to generate 300 kW of electricity using the limited capacity of the HRE-I turbo-generator, the remainder being dissipated to the atmosphere.

The damaged core vessel will eventually be replaced when the reactor has demonstrated its stability over a sufficiently long period. It was designed to hold the heavy water fuel solution of uranyl sulphate, with the surrounding blanket region containing heavy water as a reflector.

Reactor burns Pu, produces 30 MWt

Plutonium came of age as a fuel this month. Operating with a complete loading of 23 fuel plates consisting of aluminium-plutonium alloy cores clad in aluminium the Atomic Energy Commission's Materials Testing Reactor at Idaho reached its full design power of 30 MWt. The AEC reports that only minor design changes were required in the reactor, but some details of the fuel fabrication differed radically from previously used techniques. The same methods—with the addition of gamma shielding—are being employed to make a set of U-233-containing fuel elements and these are to be used in the MTR as the next stage in the programme.

The success of plutonium as enrichment for power reactors is dependent on the development of cheap reliable fuel elements and a considerable effort is being put into this at Hanford. Alloys of aluminium with plutonium are favoured because: (a) more fabrication and irradiation experience has been gathered with these than any other plutonium-containing fuel (b) there are several simplified fabrication and reprocessing schemes which can be used and (c) they are known to be similar to aluminium-uranium alloys, and advantage can be taken of the large amount of accumulated irradiation data. It is intended to use plutonium alloy as a spike enrichment loading for the Plutonium Recycle Test Reactor when it is completed in 1960. It is manufactured both at Hanford, which now has eight units, and at Savannah River (five), and Congress this year voted for the construction of yet another at Hanford.

Heavy water for hire

A policy to lease heavy water for use in domestic or foreign research, medical or testing reactors has been been revealed by the Atomic Energy Commission. Hitherto transactions have been almost entirely on a sale basis, but overseas reactor operators will now be able to obtain the initial inventory required by a reactor—with a minimum quantity of one short ton—and pay 4 pc a year during the whole of the reactor's useful life.

For US research or medical reactors heavy water will be offered for the licence period but a lease for testing reactors will have to be renewed every five years up to the duration of the period for which special nuclear material is also leased. The AEC says the new policy is designed to encourage use and development of heavy water reactors.

Borax-IV breeds U-233

Uranium-233 has been bred using thorium oxide and enriched fuel in BORAX IV, the US Atomic Energy Commission's boiling water reactor at the Idaho testing station. Announcing at Geneva that about 70 g have been produced, Joseph M. Harrer, associate director of the Reactor Engineering Division at Argonne National Laboratory pointed out that this was the first time U-233 had been made by an electricity generating nuclear power plant. He said that U-233 now contained in BORAX IV has enough energy to supply electric power to the 5000 people of the nearby town of Arco, Idaho, for a week.

——INTERNATIONAL——

EAES picks new officers

During the Geneva conference the European Atomic Energy Society held a council meeting and elected Dr Harry Brynielsson, managing director of the Swedish Atomic Energy Company, as its new president. Retiring president is Sir John Cockcroft. Other new officers are vice-presidents Felice Ippolito (secretary general of the Italian National Committee for Nuclear Research) and Jose Navascues (chairman of the Junta de Energia Nuclear, Spain).

EAES is an organization for the exchange of information on nuclear work and has been going since 1954 but all that is known about it is that it does meet periodically: what is discussed and what decided are never disclosed. Though unofficial, it functions at Authority level and its members are top executives of the national atomic energy agencies of 12 European countries—Belgium, Denmark, France, Germany, Holland, Italy, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

This was Geneva 58

Here are a few statistics on the second world conference on the peaceful uses of atomic energy :

Number of papers submitted	*2135*
Number of papers orally presented	*711*
Number of participants	*6300*
Governments and agencies represented	*78*
Tape of complete proceedings	*21 million feet*
Volumes complete proceedings in English	*33*

HUNGARY Work at the Budapest atomic research establishment is almost complete and the Soviet type WWR-Z reactor is due to go critical soon. The reactor is a tank type with a power of 2000 kW and a flux of $2 \cdot 10^{13}$. It uses 10 pc-enriched oxide and is moderated and cooled by water. Building seen here is the laboratory block, the reactor being behind

IN BRIEF

● **Brazil** An umbrella-type agreement covering exchange of training facilities and information on nuclear energy with Italy has been signed in Rio de Janeiro. Brazil is interested in the ENSI project and has opened negotiations for a similar scheme with the world bank.

● **France** PROSERPINE, a tiny homogeneous critical experiment with a core diameter of about 25 cm, has achieved criticality with only 258·1 g of plutonium, it was revealed at Geneva.

● **Germany** The first Van de Graaff particle accelerator in Europe to be used for food irradiation studies has been bought by the Technical University of Karlsruhe.

● **Italy** The contract for the construction of a 200 MWe Calder Hall type reactor at Latina (see *Worldview* June) has been signed by representatives of the Società Italiana Meridionale Energia Nucleare—SIMEA—and the UK Nuclear Power Plant Company.

● **Portugal** The first private company in Portugal dealing exclusively with nuclear engineering has been set up. Called the Companhia Portuguesa de Industrias Nucleares it is backed by twelve industrial companies, ten electricity groups and three shipping agencies. Aims are to coordinate the activities of the associated entities and to offer the construction of complete nuclear power stations.

● **Russia** An agreement has been reached with Czechoslovakia covering the supply of an experimental reactor and cyclotron and the training of technicians, states Professor Emelyanov, head of the Soviet Atomic Energy Central Administration. He says similar agreements have been concluded with China, Yugoslavia, the United Arab Republic and five other countries.

● **Switzerland** Atomic Energy of Canada is to supply eleven tons of natural uranium fuel elements for an experimental reactor and subcritical assembly. AEC has started manufacture and first elements will be ready in about six months.

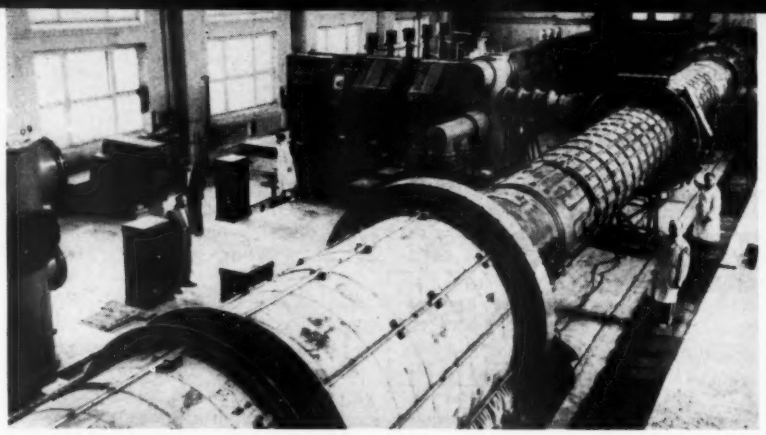
● **CERN** The first complete experiment with the 600 MeV synchrocyclotron has finally proved that a pion does in fact decay directly into an electron, announces Prof G. Bernardini of CERN. This was predicted as early as 1935 but failure to prove it has worried physicists.

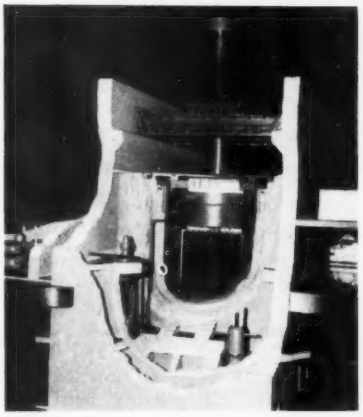
● **United States** A nuclear-powered aircraft engine has operated successfully for ten hours, though traces of radioactivity were detected in the air stream towards the end of the test, discloses General Electric's nuclear propulsion department. The engine was a General Electric J-47 turbo-jet.

● **United States** Over 3500 MW hours of electricity has been generated by the Sodium Reactor Experiment in Canoga Park, California, which has been operating continuously at full design power of 20 MWt since July 18. The reactor heat is being used by the Southern California Edison Company to generate and distribute electricity from its experimental plant adjacent to the reactor.

● **United States** A $50,000 award for 'meritorious contribution' is to keep alive the memory of Dr Ernest Lawrence, inventor of the cyclotron, who at the time of his death last month, aged 57 was director of the University of California's Radiation Laboratory.

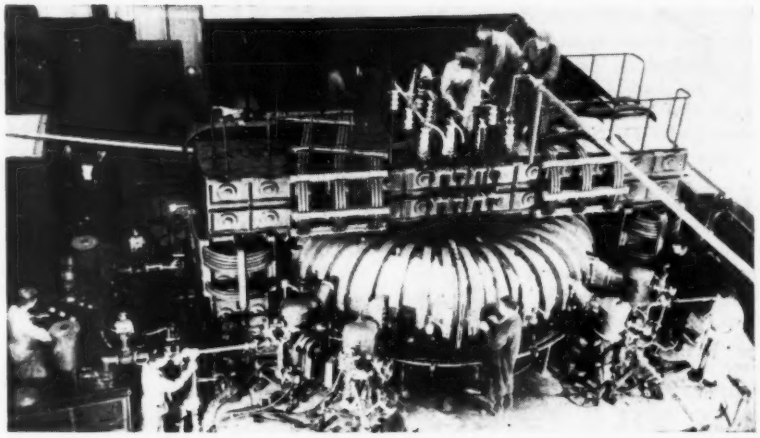
● **United States** The Argonne low power reactor (ALPR), a prototype package power reactor for space heating and electricity production has gone critical. It is a direct cycle natural circulation BWR fuelled with enriched-U and moderated with light water. Output is 260 kW electricity and 400 kW for space heat.





SOVIET UNION The biggest thermonuclear machine in the world at the moment is the OGRA (above), seen under construction at the Moscow Institute of Atomic Energy. It is a magnetic bottle machine, or adiabatic trap, in which molecular deuterium ions are injected into the centre of the huge vacuum chamber. Here most of them become dissociated and remain trapped in the bottle. In obtaining the extremely high vacuum necessary, titanium ion-getters are used. Another Russian thermonuclear machine is their ALPHA (below) which is almost identical with Harwell's ZETA.

The reactor model (left) is of a 50 MWe sodium-cooled graphite moderated plant which is said to be planned for the testing area on the Volga near Ulyanovsk. It will produce steam at 1280 psi, 935°F with sodium pressure less than 113 psi



by W. CALDWELL DAVIDSON
Editor, NUCLEAR POWER

Highlights of the Conference

—some impressions of the power sessions

NEVER HAVE SO MANY representatives, experts and observers been sent by so many nations to compare work and exchange views on any subject. Thus spoke Francis Perrin, president of this vast assemblage, in his opening address on Sept 1, 1958. As a matter of fact there were so many participants and such a mountain of papers that they had scarcely time to discuss anything at all and, indeed, Professor Perrin, closing the conference on Sept 13, said that many of the contributions should have been kept for more specialized audiences or published in the usual way. However, we had a conference on our hands and the United Nations Secretariat under Dr Sigvard Eklund kept it running without a hitch.

Classification ends

It was a conference of few real surprises but one great achievement—the US/UK declassification of all controlled thermonuclear work. The Russians were somewhat vague as to their future policy on this but Professor Emelyanov, the delegation leader, said that the papers in the five bound volumes which he presented to Dr Eklund, together with those before the Conference, represented their entire work on the subject to date. Thus one can say with a fair degree of certainty that the entire field of civilian atomic energy—with one small area excepted—has now been cleared of barbed wire, subject of course to the usual commercial considerations. The small area excepted leads into the military field and is that of gaseous diffusion. Even this is regarded as sacrosanct only by the US, the UK and the USSR.

It seems now highly unlikely that another Conference will ever be held on exactly the same lines. Views were divided on what should take its place but everyone seemed agreed that there must be something.

From the reactor sessions it emerged as obvious that Britain and France are still the only two countries with national programmes of nuclear power station building. This is not because we are particularly clever or farsighted: it is just that this is the only way we can meet our power needs during the next decade. Other countries able to design and build nuclear plants—such as America and Russia—have no pressing need for them yet awhile and can afford experiments to find the type that suits them most. This they are far from doing but it worries them not at all.

The reactor position in America was of course already well known but three papers in particular will go down as the most authoritative and useful summaries yet—*Highlights of nuclear power development in the US* (1076) by W. Kenneth Davies (ex AEC, now Bechtel Corp) and U. M. Staebler (AEC): *Experience with US nuclear power reactors* (1075) by Clark Goodman, Louis Roddis and Walter Zinn—all AEC 'Old Boys': and Norman Hilberry's masterly summary—*Full scale power reactor projects in the USA* (2447)). From these papers it is clear that, no matter how difficult, the American engineer can take a scientists's concept and make it work if required. The Americans can well afford to do this and in fact delight in doing it. But out of all this welter of reactor ideas two stand out head and shoulders—the pressurized and the boiling water reactors—as immediate propositions.

Reactor studbook

Shippingport has been criticized as producing the most expensive power in the world but this is quite irrelevant. It was never intended to be anything else than a great laboratory and there is no doubt it is a smooth, safe plant which could easily father a whole brood of machines with considerable economic attractions—if not in the US then certainly in some countries. Apart from the small Army Package Power Reactor, which seems to have given every satisfaction (and of course the fabulous submarine PWR's—strictly off the agenda at *this* conference!) Shippingport's immediate descendants are Con Ed's Indian Point N.Y. plant (275 MW total—112 from an oil-fired superheater) and Yankee Atomic's PWR at Rowe, Mass (134 MW). The interesting thing about Indian Point (Babcock & Wilcox) is that the fuel now contains thorium along with uranium in the form of mixed oxides in stainless clad pins. It is due critical late in 1960. Yankee (Westinghouse) is perhaps more like Shippingport than Indian Point. It is costing a lot more than originally estimated but the designers estimate 14 mill power eventually.

Upping EBWR still more

One of the most significant papers in the whole conference however was one on the EBWR by Harrer and others from the Argonne (2379). This reactor is going to need watching—for the direct cycle is an idea beautiful in its simplicity. As is now well known EBWR was originally designed for about 20 MWt and has now been run at well over 60 MWt with no modifications whatever. Alterations now in progress will take this up to 100 MWt and it is obvious that this is making nonsense of current economics. Harrer considers a commercial version of the boosted EBWR supplying a 33 MWe set (3 MW for house load) and concludes that the capital cost need be no more than $200/kW all-in, including a large proportion for the containment shell. A complete fuel cycle has not yet been worked out but preliminary estimates indicate a total sent-out cost of 8·43 to 9·12 mills. This, it will be noted, is only about ·7–·75d. for a 30 MW plant! Whether a direct

cycle boiling reactor would be acceptable technically in the sort of place where it would be most needed is of course another question, but last May there was a mishap with the EBWR turbine and it was possible to ship the rotor back to the maker's works for reblading with no special precautions. Similar satisfactory experience with a small boiling reactor—the Vallecitos of GE—was also reported.

Now it's superheating

The first big BWR project (180 MW) to come into operation (end '59) will be GE's Dresden, Illinois, plant for Commonwealth Edison. This uses a rather complicated dual pressure indirect cycle with rod-type UO_2 elements. It will be the largest nuclear power plant in the States built entirely with private finance and is said to be very attractive to the Italians at the present time.

The big problem with all water-cooled reactors is of course the poor quality saturated steam. Indian Point side-steps the issue by cheating on oil-fired superheating but the next big advance in the field is likely to come about through nuclear superheating. This is not going to be easy because it really means two reactors in one but one firm at least—Allis Chalmers—are working on it and are seriously considering using it in the 66 MWe Controlled Recirculation Boiling Reactor (CRBR) they are to build at Sioux Falls, South Dakota. The Russians, incidentally, are actually building such a plant. It is probable that as development proceeds the differences between the PWR and the BWR will largely disappear and a new kind of composite machine producing superheated steam will emerge. This could be a formidable challenger.

Almost every known type of reactor is under active consideration, if not actually working or under construction in the United States and it is impossible even to mention them here. There may have been a recession but in this field at least there is little sign of it. Just because they haven't got a target for so many megawatts by such and such a date doesn't mean they don't know where they're going.

Russian surprises

When we turn to Russia the situation is, curiously enough, rather similar once the rather formidable-looking and appallingly translated papers have been sifted through. The key paper to this tangle is Emelyanov's (2027) and we have tried to present this in summary form. Curiously enough, he mentioned nowhere the 600 MW six reactor station 'somewhere in Siberia' which, it was disclosed during the conference, had already one reactor working. Details of it are lacking but it seems it is fuelled with natural uranium and not to be confused with the 'blown-up' Obninsk 5 MW reactor station they are building 'in the Urals.'

Even more than the US, the USSR doesn't really need nuclear power yet, except in special areas, and this was made quite clear by Emelyanov. Nevertheless the Soviets have certainly a very ambitious programme and as far as one can judge their engineering is of a high order. One of the few real surprises of the Conference, for example, was the disclosure that the *Lenin* icebreaker—she is due for criticality trials next month and to go to sea in the spring—has actually three pressurized water reactors. Packing 44,000 shp into her 1600 tons, *Lenin* is probably the most highly powered ship in the world and is designed to do 2 knots through ice *7 ft thick!* It is probable that the Russians are mass producing these PWR's as submarine units.

Perhaps the most significant Russian power development is the proposal to use nuclear superheating in their big graphite-moderated plant now building in the Urals. This is a direct descendant of the 5 MW Obninsk reactor which is now running with 70 of its 128 channels boiling, and whose rather complicated fuel element has proved remarkably reliable. The new Urals plant is designed for a fuel cycle (1·3 pc enrichment) of 730 days and the fuel component of cost is estimated at 30–40 pc of the total. Actual unit costs are difficult to obtain but Emelyanov gave an expected figure of 7 kopecks compared with 5–12 kopecks for conventional power plant. Capital costs of nuclear stations would be 20–30 pc higher than conventional ones, he said.

Canada's new way

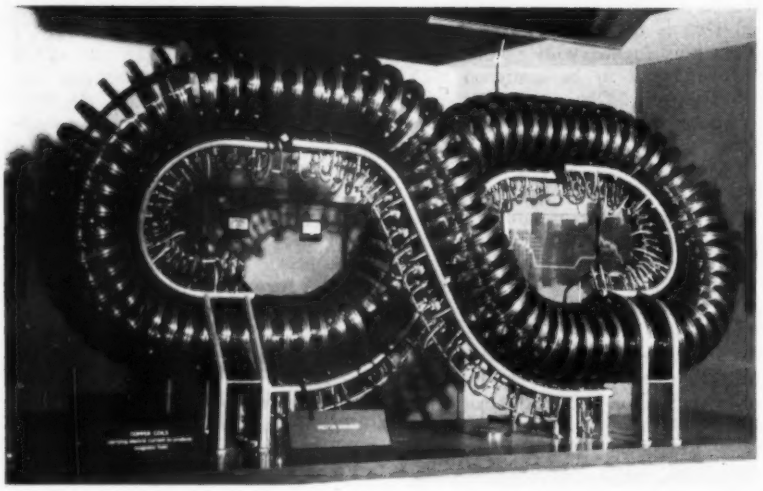
The French effort, while in some ways similar to the British in that they are concentrating on natural uranium gas-cooling is rather more diversified in outlook, G-II, EDF-I and EDF-II being very different machines. G-II's horizontal arrangement and prestressed concrete shell in particular seem to have been completely abandoned and, in fact, EDF-II with its 70 ft dia. spherical shell is beginning to look uncommonly like a British reactor, although the pressure—nearly 300 psi—is very much higher.

One of the highlights of the Con-

Guide to Soviet Power Stations

PLACE	TYPE	REACTORS	STATUS	NOTES
Moscow (Obninsk)	*Graph-mod H_2O-cooled*	*1 5 MWe*	*1954*	*First atomic power station*
Voronezh	PWR	*2 210 MWe*	*const'n*	*3 turbines per reactor*
Leningrad	PWR	*2 210 MWe*	*const'n*	*Similar to above*
Siberia	*Graph-mod H_2O-cooled*	*6 100 MWe*	*No 1 Sep '58*	*Natural U*
Urals (Beloyarsk)	*Graph-mod H_2O-cooled*	*4 100 MWe*	*const'n*	*Development of 1st station with nuclear superheating*
Volga Centre (Ulyanovsk)	*direct* BWR	*1 50 MWe*	*const'n*	*Similar elements to* PWR
Volga Centre	SGR	*1 50 MWe*	*planned*	
Volga Centre	*Fast*	*1 50 MWe*	*planned*	*Type BN-50*
(not chosen)	*Fast*	*1 250 MWe*	*planned*	*Type BN-250*
(not given)	*Intermediate*	*1 50 MWe*	*const'n*	*flux of 2×10^{15}*
Moscow (Obninsk)	PWR	*1 2 MWe*	*compl. Dec '58*	*mobile plant*
Volga Centre	*Homogen.*	*1 35 MWt*	*const'n*	*Oxide in D_2O Boiling cycle*
Czechoslovakia	*CO_2-D_2O*	*1 150 MWe*	*planned*	*3 150 MW sets*

Liquid metal fuel and organic cooled types are also planned and consideration is being given to a transportable high-temperature, gas-cooled reactor with ceramic elements and nitrogen or hydrogen cooling.



A figure-eight stellarator by Princeton University, this demonstration model showed by a beam of electrons how a plasma is given a rotational transform to ensure stability. Later models achieve same effect by helical windings on a 'race-track' torus. Heating in a stellarator is achieved mainly by magnetic pumping

ference was certainly W. B. Lewis's account of how Canada proposes to achieve 6 mill/kWh nuclear power using a simple once-through fuel cycle with no value whatever placed on used fuel elements. Canada is now firmly wedded to the heavy water approach and, with oxide fuel and bidirectional fuelling in the horizontal pressure tube reactors of the NPD-II type, this is believed to be the formula for success. It may well be, for Canada at least.

Britain stays with gas

Turning now to Britain, so much has been published on the first round power stations that, wisely, the papers on these were not read but merely tabled for the record. There were however several excellent contributions—mostly from the Authority. Sir Leonard Owen, for example, covered some aspects of the Authority's work during the last 10 years (30) while William Strath gave a very well argued account of our plans for the future (26). He made it pretty plain that the Authority have little intention of doing much about liquid-cooled reactors for civil use in the near future—except for a heavy-water gas-cooled project. On the subject of enriched fuel he was rather vague and although he admitted that some would be necessary he gave no indication of where it is to come from, or at what price.

One thing that is going ahead is however the Advanced Gas Cooled reactor and R. V. Moore and colleagues from Risley (312) gave first details of this machine, the prototype of which is to be built at Windscale. These are reported elsewhere in this issue but this was only a small part of Moore's paper which was a general review of British reactor *rationale*. Much the same ground, although with the sights lowered to cover what is actually going on now, was covered by J. B. W. Cunningham in his paper on the current redesigns of Calder Hall (73) in which he shows how the outputs and rating of the first round stations were increased so dramatically.

Apart from Moore's piece about the AGR however, the most interesting British reactor paper was undoubtedly the one on the High Temperature Gas Cooled Reactor (314) by Shepherd and others from Harwell. This is disclosed as an extremely elegant and advanced concept for about 750°C, working with all-ceramic elements on the Th-232/U-233 breeding cycle cooled with helium. The 10 MW reactor experiment, which will probably be built as an OEEC joint effort, incorporates the ingenious thermodynamic device of a free-running gas turbine/blower set, the heat rejected from the turbine going to a heat exchanger for further utilization.

Choice still wide

If after the 1955 Conference the reactor situation looked confused it is certainly not one whit clearer today. Most of the machines described then were just projects: now many of them are working—and working well. It will obviously be many years before the field of economically attractive, practical systems is narrowed to 'normal' types. This is of course no bad thing and meanwhile invaluable experience is being gained, not only on the reactors themselves but in the multitude of ancillary technologies that go with them.

One striking feature of the nuclear power situation is the extraordinary abundance of uranium now disclosed. Sir John Cockcroft, for example, in his conference summing-up put world reserves in the order of 10 million tons in high grade deposits: shale and phosphate deposits being virtually unlimited. The high-grade reserves Sir John estimated at equivalent in energy to four times the known coal reserves. 'We are likely,' he went on, 'to have developed fusion power long before we run out of uranium.' World prices are foreseen as stabilizing at around $8 a pound of oxide ($U_3O_8$).

Non-military uses of nuclear explosions was the theme of a paper by H. Brown & G. W. Johnson of the UCRL (2179) and they were later backed up in this by Willard Libby. This concerned the US Plowshare programme under which it is proposed to carry out what Edward Teller describes as 'geographical engineering'—or the alteration of natural features on a grand scale. Libby's main interest was that an underground explosion could produce, in an instant, a supply of isotopes which it would take an expensive reactor years to produce.

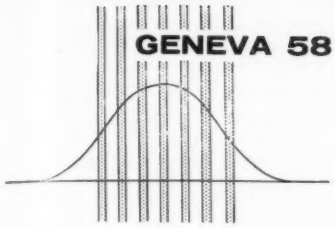
The really big problem

Apart from the opening session—a purely formal occasion—the best attended general session was the one on controlled thermonuclear fusion and excitement rose visibly as the time for the Soviet paper by Artsimovich came near, because few if any of the participants had seen it in advance. It came as a complete anticlimax—no, they had not done it yet. 'It' being the achievement of a genuine thermonuclear reaction; 'they' being the Russians.

At this stage it is quite impossible to say which country is 'ahead' in this fascinating race. The Americans seem to have more machines than anyone else: the Russians have easily the largest and most powerful in OGRA but it's brand new and hasn't had a chance yet. Although we were first in the field, British work has so far been on rather a narrow front.

What it meant

The above is merely a subjective impression of just a few of the topics covered by this great Conference. In other articles in this issue specialists have attempted what can only be regarded as interim reports, simply answering the question 'what happened?' What all these advances really *mean* will take time and close analysis and this we hope to do in due course.



by H. H. GOTT, E. F. O. MASTERS and G. C. SHIPP
Central Electricity Generating Board

Power reactors

— advances reported from many countries

THE PERIOD since the first Geneva conference has been marked by the coming into operation of a number of power plants of considerable size, and the operating experience now reported is extremely encouraging. Nuclear power economics now appear to have a surer foundation, although for detailed estimates of long-term costs of electricity from any specific installation, we are still relying, to an extent which is unknown in conventional plants, on the confidence of designers, and on extrapolation of experience of fuel burnup and reactor serviceability which, although encouraging, is not yet quite adequate for certainty. It could not be otherwise and in this respect the situation cannot change materially for some years. But the mood of the present conference differed somewhat from the first in that we are now discussing reactors less in terms of optimism or pessimism and very much more in terms of hard work, and effort both reported and to come.

GAS-COOLED REACTORS

Calder Hall

A detailed description (1522) was given of the methods of the start-up and control, and of the performance of plant components. Considering that Calder has to shut down for fuelling and that the fuel turnover is relatively extremely high, because of its plutonium production, the plant has a load factor history which is quite remarkably good. It has been concluded that no Wigner energy release is at present necessary, but a drill for doing this has been worked out and tested. The plant operation has proved very straightforward and the behaviour of the fuel and of the burst cartridge detection gear has been good. It was reported verbally that there have only been four or five cartridge failures altogether, and no contamination of the circuit had resulted. As burnup proceeds, the moderator temperature coefficient becomes positive, and although theoretically this is a most important point, in practice reactor control is little influenced. Detail difficulty has been experienced in adjusting the coolant flow and temperature in each channel and it is thought that a more elaborate thermocouple installation would have been justified. The fuel charging machinery works rather more slowly than had been hoped, and some useful modifications and simplifications have been made. The reactor conditions are sensitive to the feed water conditions and improvements in feed water regulation are at present in hand. In response to a direct Russian question, Sir Leonard Owen stated that a very large number of fuel elements were allowed to remain in the reactor for long periods, being removed gradually for examination. There were at present some hundreds of cartridges which had reached 1300 MWD/te without trouble and detailed metallurgical examination showed there is no reason to expect trouble before very much higher burnups.

Two years of G-I

The first reactor at Marcoule was built and commissioned very quickly at a time when information in France was very limited, and its performance has not reached expectations. This is mainly due to deficiencies in fuel element heat transfer which would be simple to rectify with a new charge of fuel if the pressure rise in the blowers would permit it (1132). Difficulty has been experienced in the fuel handling equipment, from which the authors give the following warning:—

Also there is inherent difficulty in the adoption of devices which are too closely related to precision mechanics, not to say the watch-making industry.

The design of G-II (1133) which is now in operation, also shows lack of time for development—construction began before G-I was completed. The pressure of the carbon dioxide is kept slightly above that of the steam in case of leaks in the exchanger, and G-I's horizontal arrangement of fuel channels is retained. Widest departure from British practice is the use of prestressed concete lined with relatively thin steel for the pressure vessel to bypass the welding problems associated with thick plates.

British commercial stations

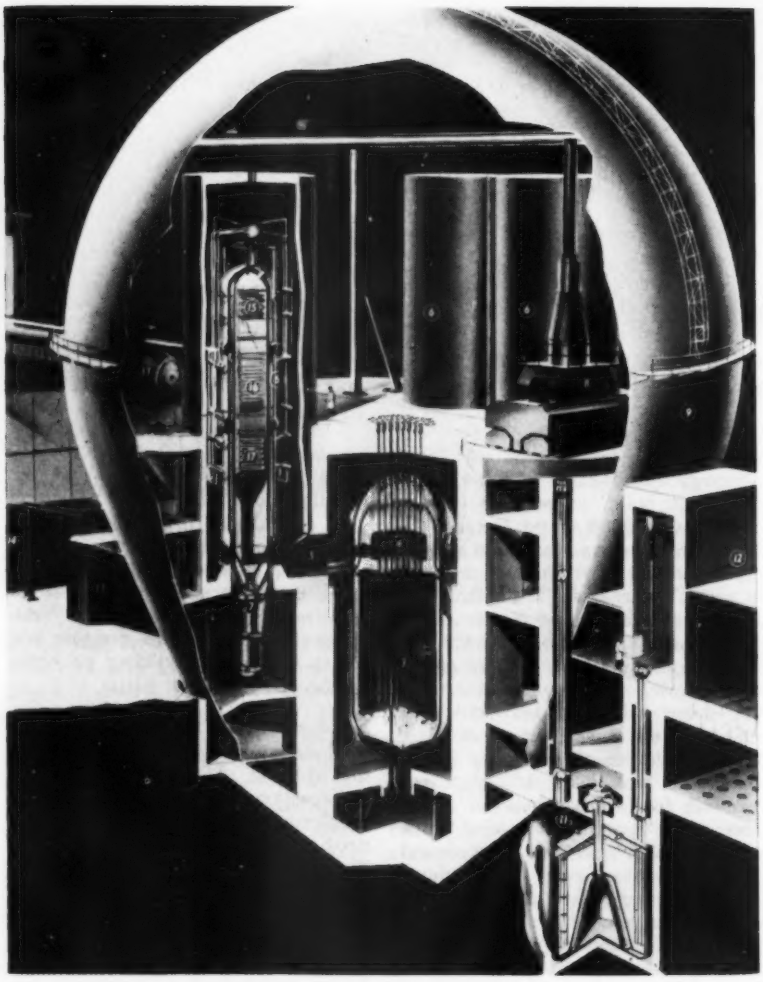
There are a number of papers dealing with the stations currently under construction — Berkeley, Bradwell, Hunterston and Hinkley Point—that need not be referred to in detail here. They cover problems of fuelling (37), kinetics and control (55), overall control (85) and design philosophy (75, 263, 264). The opportunity is taken, in some of these papers, to publish design parameters not hitherto reported. A further paper (73) from the AEA describes the Authority's method of design assessment and discusses the various factors responsible for the great improvement in station performance.

French commercial stations

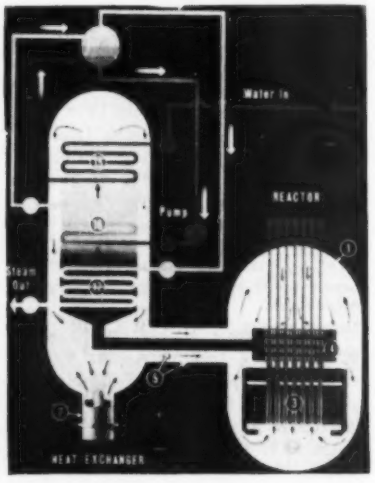
The Chinon plant (EDF-I and EDF-II, paper 1135) is designed as a full-scale industrial station for the generation of power and it is hoped that the EDF-I will be in service in mid-1959, with EDF-II following 18 months later.

The EDF-I core of 8·3 m active diameter (9·5 m overall) is 10·2 m in height and contains 1,148 channels in three zones. These three zones arise

ZONE		A	B	C
Inside radius	m	0	1·80	3·10
Outside radius	m	1·80	3·10	4·15
Spacing	cm	19·6	22·4	22·4
Channel diameter	cm	8·4	8·4	8·0
Rod diameter	cm	1·4-3·5	1·4-3·5	3·2
No. of channels		256	412	480
No. of slugs		3840	6180	7200



Advanced Gas Cooled Reactor. First view of Britain's new project shows plant layout (above) and flowsheet (below). Note concentric gas duct and heat exchanger. First contracts have been awarded. 1 Reactor vessel 2 Cool gas entering core 3 Fuel elements in core 4 Hot gas leaving reactor 5 Ducting 6 Heat exchangers (4 off) 7 Co_2 circulator 8 Re-fuelling machine 9 Containment building 10 Fuel access tube through containment building 11 Carousel 12 Fuel element building 13 Air locks 14 Control room and turbine hall 15 Economiser Bank 16 Evaporator bank 17 Superheater bank



because two lattice pitches and two channel diameters are employed. In addition, two types of fuel rod are used, there being 15 rods per channel with each rod 60 cm in length. The main core parameters are shown in the table.

It will be noticed that the inner two zones contain tubular elements, while the outer zone has solid rod elements. Zone A has a smaller lattice pitch, concentrating fuel in the centre of the core, and Zone C has a narrower channel, giving a higher local outlet gas temperature. The channel inlets are gagged to give design inlet and mixed outlet temperatures of 140°C and 355°C.

The double lattice is employed in order to achieve a large flattened radius without absorber. The packing of uranium in the core centre flattens the flux which, given a limitation on maximum permissible rating, leads to an increase in the mean specific rating and zone conversion factor and for a given reactivity allows a larger flattened radius to be used. Theoretically the available reactivity would allow 35 pc extra fuel per unit volume, but 30 pc is actually used to allow for uncertainties in the calculations. Absorber will be used if found necessary. The advantages of this method of flattening are somewhat reduced by the flux curve irregularity at the zone boundary.

The natural uranium fuel is canned in magnesium alloy for a design maximum can temperature of 400°C and a uranium centre temperature of 550°C. There are 17,220 elements.

The core is contained in a vertical cylindrical vessel with hemispherical ends fabricated from a manganese-molybdenum alloy steel similar to ASTM A302A. The main dimensions of this vessel are given below.

Inside diameter	10	m
Cylinder height	13·4	m
Overall height	22·8	m
Average shell thickness	107	mm
Average thickness—top	59	mm
Average thickness—bottom	54	mm
Weight, including insulation	773	te
Coolant gas pressure	356	psia

The plant is designed on the unit system—one reactor, one main circulator, one main heat exchanger, one generator — but there are auxiliary safety cooling circuits. Since the plant generates 74-82 MWe according to conditions, this means that the single circulator is of considerable size. It is a single-stage axial machine operating at a constant speed of 2980 rpm with flow regulation by variable baffles. The design conditions are:

Flow rate	3350	lb/s
System pressure	358	psia
Pressure rise	23	psi
Outlet temperature	140	°C

The circulator is driven by two asynchronous squirrel cage motors totalling 9620 kW.

The heat exchanger is of a multitube design, shop-fabricated, with both pressures of the dual cycle below the gas pressure to avoid water leakage into the coolant. It generates steam at 313 psi/342°C and 57 psi/215°C for a net turbine efficiency of about 20 pc.

For safety reasons the whole of the reactor, heat exchanger and auxiliary circuits are enclosed within a 55 m diameter containment sphere, largely of 20/21 mm plate, with the reactor itself surrounded by a thermal shield of water (1 metre thick) and a concrete wall.

Development of fuel elements

A notable feature of the British commercial reactors under construction is the considerable increase in output compared with Calder Hall, which may in part be attributed to the development of improved fuel elements. This aspect of reactor design is obviously very important and it is interesting to find that a number of papers are devoted to this subject, giving significant disclosures of development work done by the industrial design groups.

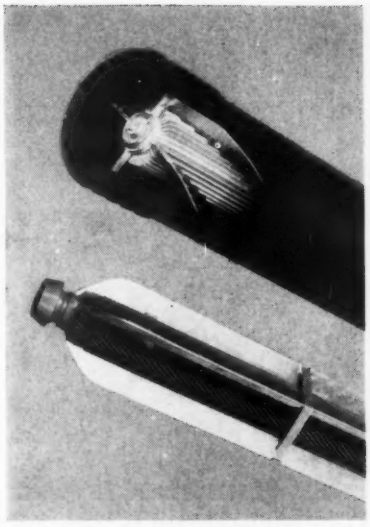
It is well known that in a gas-cooled reactor using ratings sufficiently high for economy a large gas flow is required in each cooling channel. Two approaches to this problem are disclosed in the fuel elements for the Bradwell and Hunterston stations whilst showing at the same time two quite different approaches to the problems of mechanical support of the elements.

Development of the Bradwell element (48)—a polyzonal spiral type—led to a design which is essentially a multistart helically finned can with longitudinal zoning splitters. Both thermodynamic and mechanical aspects of the work are covered in the paper. In contrast, the Hunterston development (610) resulted in an independently supported element (carried in and supported by a graphite tube integral with the element) with longitudinal fins and with the flow broken up by spiral mixers slotted over the basic fins.

Of particular importance is the UKAEA approach (306) to assessment and testing of fuel element designs put forward for power reactors. It also deals with the proving of production techniques and non-destructive testing methods.

Future prospects

There are several papers on this subject (1463, 273, 314) but only one needs to be mentioned at length here. Paper 312—Advances in the design of gas-cooled graphite-moderated power reactors—sets down the lessons learned from Calder Hall and then discusses the future of the system, dealing in particular with fuel cycles, slightly enriched reactors, use of oxide fuel and the development of high temperature operation. The advanced gas-cooled reactor project (AGR) due for completion in 1961 is briefly described and its main parameters given, some of which are set out below. This will have CO_2 cooling and the first charge will be UO_2 canned in beryllium.



Examples of British fuel elements show two approaches to the same problem. GEC (above) use straight can fins, helical splitters: NPPCo (below) have twisted fins, straight splitters

AGR MAIN PARAMETERS

Reactor heat	100 MW
Net output	28 MWe approx
Core length (excluding reflector)	14 ft
Core diameter (excluding reflector)	15 ft
Channels	250
Gas pressure (reactor inlet)	270 psig
Gas temperature (reactor inlet)	250-325°C
Bulk gas outlet temperature	500-575°C
Mean fuel rating	7·75 MW/te
Maximum fuel rating	18·00 MW/te
Steam conditions	620-670 ps.g/860°F
Maximum can surface temperature	600°C

This reactor is of special interest as it may be considered to have the same relationship to the next family of reactors built in the UK as has Calder Hall to the stations now under construction.

HEAVY WATER REACTORS

The several papers dealing with this subject (246, 209, 135, 559) allow a comparison to be made of the different approaches and it is instructive to compare the conclusions reached. Great attention is given in the designs to the safety of the surrounding area in the event of an accident and the accent is therefore on containment and ventilation, with plant halls maintained slightly below atmospheric pressure so that leakage is inwards and controllable and with air-locks between different sections of plant.

The reactors under discussion—NPD-II (Canada), Sulzer Project (Switzerland), R-III (Sweden) and Halden (Norway)—are all experimental or pilot in nature. Because of this it is difficult to arrive at the likely cost of larger full scale reactor systems, but the Canadian paper puts forward estimates of costs for a 200 MWe station. The capital cost is given as $310/kW with a fuel cost, for an assumed burn-up of 7000/MWd/tonne of 2·2 mills per kWh.

Canada

NPD-II—the successor to the now abandoned pressure shell NPD-I—which is due for completion in 1961 may be looked upon as a natural development from the satisfactory experience with the NRX research reactor. It is a 20 MWe pressure tube design with horizontal aluminium calandria and was conceived as a pilot for 150-300 MW reactors. A significant innovation is the provision for on-load bidirectional fuelling.

The Sulzer Project

The Sulzer project is to be situated in Zürich and will yield 30 MWt for electricity generation or for use with an existing district heating scheme. It is a pressure tube design, in which the coolant and moderator (both heavy water) are separated by a pressure-carrying wall. The fuel (5 tons) is predominantly natural uranium metal, and the core comprises 88 elements on a square lattice, with 9 control rods.

The R-III Reactor

This reactor is a prototype for a commercial unit for district heating and electricity generation. It is not expected to be an economic proposition and it is too early at this stage to say what the level of generating costs is likely to be.

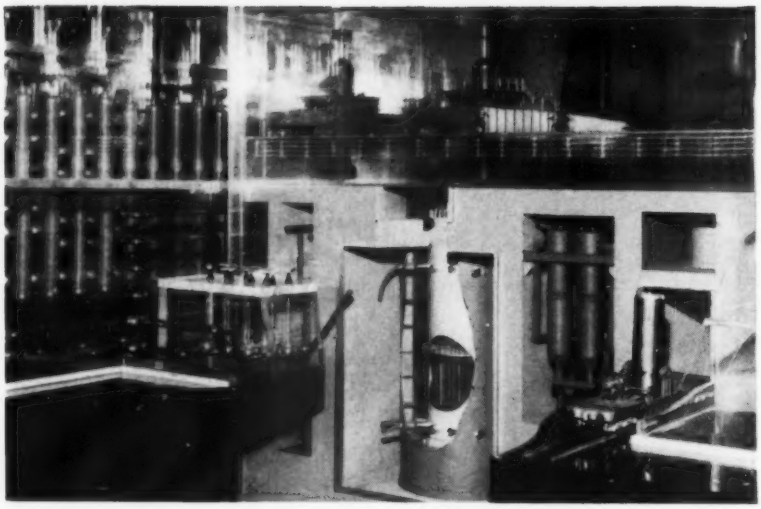
60-70 tons of heavy water comprise moderator, reflector and coolant, working at 35 atmospheres between the temperature of 205°C at the reactor inlet and 220°C at the outlet. This generates sufficient saturated steam at 15 atmospheres to provide 10 MWe from a back pressure turbine and 55 MWt for a district heating scheme. It is planned that finally this 65 MW will be increased to 125 MW and that an oil-fired superheater will be incorporated.

The fuel (15 tons of natural uranium) is in the form of oxide pellets sheathed in Zircaloy-2. The fuel element consists of 5 bundles of 18·4 mm diameter rods, each bundle containing 19 rods with a minimum centre to centre spacing of 22 mm. There is provision for on-load fuel handling.

The Halden Reactor

This reactor differs from those mentioned earlier in this section in that it is a boiling reactor. It will be purely experimental and will take no turbine load. The design output is 10 MWt.

Inside a reactor vessel of 2·7 m diameter is fitted a hexagonal lattice



Czechoslovakia is planning this Soviet-designed 150 MWe heavy-water gas-cooled power station. There are twelve gas circuits with 24 heat exchangers and four circuits supply each of the three turbogenerators. Ten percent of the moderator is evaporated and recondensed every 24 hours for clean up. Note water shield—a common feature in all Russian power reactors

with 130 mm centres, giving 325 lattice points, of which 19 are reserved for cadmium control rods. This lattice can be changed and indeed the pressure vessel itself is so designed that it can be removed.

The fuel is natural uranium metal (25 mm rod) in finned aluminium cans 2·4 m in length. The maximum temperature for these elements is 150°C, because of corrosion problems, but in any case it is thought that enrichment would be necessary to reach this temperature.

Heavy steam is generated at 28·5 kg/cm² and 230°C which in its condenser raises light steam at 205°C and 17·5 kg/cm². The total amount of heavy water in the system is some 16 tons.

Theoretically this reactor should have a strong negative steam void coefficient, but experiments have indicated that other, unknown, effects may be important. One of the first tasks of this reactor will be to provide the required information on the connection between steam voids in the boiling coolant and reactivity. It is hoped to commence these experiments in December 1958.

ORGANIC MODERATED REACTORS

While not a prototype for a power reactor, OMRE (421) is of particular interest as a full scale irradiation facility for studying organic moderators.

The elements are of plate-type stainless steel—uranium oxide construction, with a temperature limit of 800°F, over which the moderator-coolant flows at a maximum velocity of 15 ft/sec (to minimize erosion) at 200 psia between inlet and outlet temperatures of 500°F and 517°F. The circulation rate is 9200 gpm.

Early results with OMRE show the organic material has good chemical stability under irradiation and its low induced activity has allowed accessibility of the primary circuit for maintenance even while the reactor is on full load. Further work is going ahead to enable an assessment of large reactor economics to be made.

PRESSURIZED WATER REACTORS

The Shippingport PWR (1075), has been operated satisfactorily since its start up in December 1957. It is interesting that from criticality to full power (60 MWe net) occupied three weeks only.

This reactor has a multiple-region core, there being a ring seeded with enriched uranium which has natural uranium fuel both inside and outside it. This seed material can be discharged without removing the top of the pressure vessel, but it must of course be shut down. Start-up occupies 1 to 1½ hours.

In general, the PWR is showing very good stability and handles large load changes without strain. To illustrate the point paper 2462 says:

During preparation for shut down after a run and while the plant was still at 60 MW net output, condenser vacuum was lost. This causes the turbine to shut down automatically, but does not result in a reactor scram. As a result without any movement to control rods, the negative coefficient reduces the reactor output to essentially zero. The only significant effect on the plant was an increase in pressure from 2000 to 2160 psi. This is below the set point of any reactor plant relief valves, therefore, no relief valve lifted during the transient.

The primary circuit activity dies down very quickly at shut down, to a tolerable level and during the operation of several reactors of this type no long life activities of uncomfortable magnitudes have been observed. Long term experience with burnup is missing but there is every indication that a satisfactory life will be obtained.

A new core is being manufactured for Shippingport and it is expected that this will enable the gross electrical output to be increased to 100 MW and, in addition, will improve the fuel lifetime considerably.

The APPR-I

Another American PWR described was the Army Package Power Reactor (1926) and it was reported that the load was cycled from 200 kW to 2100 kW, i.e. from below 10 pc to rated full load, six times in 75 minutes. During the course of these load changes no adjustments were required to the control rod positions since the temperature coefficient effects maintained the reactor power at the appropriate level.

Indian point

An unusual feature of this plant (1885) is the use of an oil-fired superheater to increase the plant output from 163 MWe to 275 MWe. The generation costs forecast are approximately 1·5d/kWh with saturated steam and 1·16d/kWh with superheated steam. It is due operational late '60.

The reactor core is an internal thorium converter, cooled and moderated by H_2O. The fully enriched uranium oxide is mixed with the fertile material (thorium oxide) and formed into pellets which are clad in stainless steel tubing to form the fuel elements.

During the estimated core life of 600 full-power days approximately 64 kg of U-235 are burned as supplementary fuel, and 150 kg of U-233 and 15 kg of Pa-233 remain in the spent core.

The design assumes the following values for critical parameters:

no local boiling in any channel at 100 pc power
no net boiling in any channel at 125 pc power
maximum fuel centre temperature not to exceed the melting temperature (5800°F) at 125 pc power.

It is intended to use soluble poison to control the reactivity effect of temperature, as well as to provide an

additional shut-down system. It is removed by dilution during the primary loop warmp-up period. The burnable character of this poison provides a degree of compensation for depletion during the core lifetime.

The overall plant control is based on a constant turbine stop valve steam pressure rather than the more normal constant mean temperature control system. Variations in steam pressure will cause the control rods to vary reactor power in such a way as to re-establish datum steam pressure.

BOILING WATER REACTORS

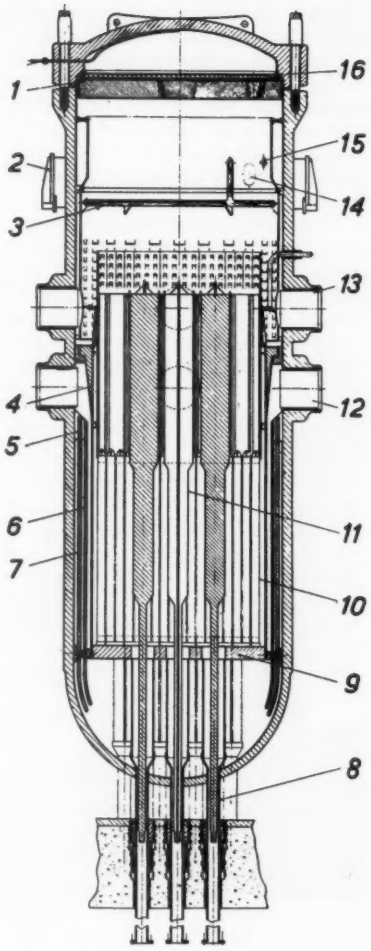
These types have shown very satisfactory stability and under normal operation have a large margin against reactivity instability due to variation in moderator density. With direct cycle boiling it has been shown that during normal operation the radioactivity in the turbine is a minor and entirely management problem. But this has not yet been established when there are burst elements.

Economics of direct systems is favourably influenced by the elimination of part or all of the heat exchanger, and details of experience with this cycle, together with an outline of important factors is given in papers 1923 and 2372. A further major economic factor is the practical power density attainable without the onset of instabilities, and a method of determining stable power limits has been developed (2379) A further dynamic problem peculiar to the direct cycle BWR is the effect of changes in steam flow or pressure on the reactor stability since there is not the interposing thermal inertia of the heat exchanger.

The Dresden plant

The big BWR now building at Dresden, Illinois (complete mid '60) is the largest all-nuclear plant—180 MWe—yet scheduled in the USA. To be operated by the Commonwealth Edison Company, it is designed and built by the General Electric Company, and aspects of the design and expected performance are dealt with in paper 2372 It is estimated that, excluding the cost of research (33 pc of the total), the energy from this station will cost about the same as power from the latest coal-fired plant on the Company's system.

Dresden is unusual in using a dual pressure steam system, the h.p. steam being taken direct from the drum fed with steam from the reactor vessel. The l.p. steam is obtained from a heat exchanger in which the feed is evaporated by heat transferred from the h.p. drum.



Planned jointly by a US/Belgian group, this 242 MWt boiling water reactor will produce saturated steam at 650° psi which will then be raised to 1050°F in an oil-fired superheater. 1 Inside shielding plug 2 Core vessel support 3 Cooling water distribution ring 4 Core collar 5 Thermal shield support 6 Inner thermal shield 7 Outer thermal shield 8 Tube of control rod 9 Grid supporting assemblies 10 Fuel assembly 11 Control rods 12 Main circulation inlet pipe 13 Main circulation outlet pipe 14 Steam outlet pipe 15 Water level pipe 16 Shock absorber plate

Details of the main plant parameters at rated load are:

gross generator output	192 MW
net sent out power	180 MW
reactor heat rate	626 MW
net plant heat rate	11,880 Btu/kWh
reactor pressure	1015 psia
primary steam pressure	990 psia
secondary steam pressure	510 psia
feed temperature	405°F

In order to maintain water purity, s.s. cladding is used on all surfaces in contact with the primary fluid.

To maintain the high water purity necessary to reduce contamination throughout the primary steam system, including the turbine, three water treatment systems are used. The make-up water, drawn from deep wells, is treated in separate bed demineralizers with a decarbonator and in mixed bed, polishing demineralizers. The reactor clean-up passes a portion of the condensate through a mixed bed demineralizer. All the condensate fed to the reactor system primary steam drum is passed through a mixed bed demineralizer.

In addition to the conventional scram by control rods, the reactor is provided with an emergency poison system which ensures shut-down in the event of failure of normal shut-down rods by injecting sodium pentaborate solution into the reactor core. These features coupled with complete plant containment make the design very safe.

The fuel is slightly enriched sintered UO_2 pellets in Zircaloy-2 tubing, operating at a maximum centre temperature of 4570°F.

Heat transfer and other data of interest are:

average heat flux	94,660 Btu/ft²
max heat flux (hot spot)	346,000 Btu/ft²
average power density (in-core coolant volume)	1390 kW/ft³

Turbine design is aimed at attaining an availability comparable with conventional sets in spite of the wet steam and free hydrogen and oxygen. To attain this, moisture separating devices are self-contained within the turbine, and the stage energy and pressure drop in the h.p. stages are approximately half the normal design values.

Boiling water reactors are showing considerable development potential (2372). Suggested improvements include the use of nuclear superheating, a supercritical pressure cycle, increase in specific power rating arising from improved fuel element design, and a plutonium recycle system to make the plant independent of enriched uranium. Aimed at cost reduction a 200 MWe BWR project proposes a single steam cycle and the use of liquid poison for control, this latter feature allowing simplification in plant design.

A detailed evaluation (2379) of the direct cycle BWR based on EBWR and BORAX IV data and performance, shows the importance of stability and power density criteria is of major importance in these plants. The paper sets out a critical examination of this using the frequency response technique. Of particular interest are the results of measurements of activity in the turbines and feed systems of these plants. The principal activity in the EBWR system arises from N-16 which in turn re-

sults from the O-16 (n,p) N-16 reaction. The half life is 7·4 s and therefore has little effect on maintenance work during shut-down. After 2840 hours running during the past year the turbine of EBWR was opened up for inspection. The radiation survey taken ten days after shut-down revealed no radiation hazard arising from loose radioactivity on the steam and feed plant.

The conclusion of the evaluation is that as a result of the information available from BORAX-IV and EBWR, a direct cycle BWR with a net output of 30 MWe could be built for as little as $200/kW (£72/kW), a figure which compares favourably with conventional plant of the same output. However, because these cores will require an average enrichment of 2·5 to 3·5 pc, the cost of energy may not necessarily be economic. Tentative unit cost figures from the proposed 30 MWe plant, based on 80 pc annual load factor and 15 pc capital charges come out at slightly less than 0·8 pence per unit sent out.

Spray Evaporation

In connexion with steam void reactivity coefficient the interesting paper on spray evaporation may be mentioned (1451). This recognizes that 'chugging' of boiling water reactors results in roughness in power control and may lead to divergent oscillations. It is thought that this is a characteristic of all boiling systems operating above a limiting power density and that it is associated with steam void fraction in the core.

The suggested answer to this is a new method of steam generation where the liquid is dispersed in the steam instead of vice versa. Experiments have shown that this system gives heat transfer coefficients of the order of 5,000-10,000 Btu/h/ft²/°F depending on conditions.

FAST REACTORS

A broad measure of similarity between many aspects of the Enrico Fermi and Dounreay fast reactors is indicated by papers 2927 and 274. On the other hand the marked differences in the fuel elements are brought out. The Dounreay elements are tubular and allow internal cooling, whereas the Fermi core uses 0·158 inch o.d. pin elements clad in 5 thou zirconium.

Both papers refer to the instability likely to arise with long unsupported elements due to the differential expansion arising from the power density variation across the core, and describe basically similar solutions for restraining the element movement at the core centre, although the detailed methods of accomplishing this differ somewhat. Comparison of the heat flux in the two plants indicates that the Dounreay value is somewhat higher than that of the Fermi This fact may also explain the correspondingly lower primary coolant outlet temperatures and steam conditions of the Dounreay plant.

In the case of the Dounreay secondary heat exchangers (Na to H_2O), a design which precludes the possibility of contact between the water and sodium has been used, the water and sodium flowing in separate stainless steel tubes thermally connected by copper bridge pieces. The Enrico

Shown at the scientific exhibition was this full size core in metal for the Soviet BR-5 fast reactor. It uses plutonium oxide fuel and, since it is not intended for breeding research, the reflector is nickel, with only a small layer of uranium. It is a study for the BN-50 power breeder

Fermi secondary heat exchanger is of the more simple shell and tube design, and the authors state that small amounts of leakage of water into the sodium system can be dealt with and the leak located and rectified.

Estimated costs of the Fermi plant (2427), including heat exchangers and boilers, amount to the surprisingly modest figure of about £123 per kWe. The cost of energy from such a plant would include the additional cost of the turboalternator plant, etc and the fuel cost. This latter is stated as being 3·5 mills/kWh (0·3 pence/kWh) at 2 pc core burnup, and varying from this figure nearly inversely proportionally to the burnup. This indicates that a burnup in excess of 2 pc would be required to make this form of power production competitive with alternative methods.

No forecast of the ultimate burnup that will be attained is given in the paper, and presumably one of the primary objects of this reactor is to establish an answer to this particular query.

SOVIET REACTORS

The reactors described by the Russians in their very late papers (2027, 2139, 2183, 2184) are in general water-cooled, though the successful operation of a small sodium-cooled fast reactor was also mentioned.

The first 5000 kWe station at Obninsk, near Moscow, has continued in satisfactory operation, having over four years to its credit (2183). It has been operated using fuel shuffling or partial reloading to equalize burnup, and (using, of course, enriched uranium) burnups up to 23,000 MWd/ton are claimed, the elements remaining serviceable. A reactor of this type using a dual steam cycle using reactor heat for steam superheating (2139) is reported to be under construction. It will produce 100 MWe from one reactor.

For large power plants, at present there is some concentration on the pressurized water reactor, or as the Russians call it, the water-water reactor (2184). At least two of this type are being built, and initially they are to operate with no boiling in the channels, though it seems that subsequent development of a boiling type is foreseen. These stations will each have two 210 MWe PWRS. One is near Leningrad, the other at Voronezh. The limiting factor in design is described as the melting point of the oxide, 2800°C. The rating and element diameter are so chosen that under the most unfavourable combination of circumstances such as dimensional tolerances (but under steady state conditions!) the centre fuel temperature does not exceed 2200°C.

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1522 *UK* Operating Calder *Davey et al.*
37 *UK* Fuelling Calder *Colmer et al.*
55 *UK* Berkeley kinetics *French et al.*
85 *UK* GC reactor control *Smith*
75 *UK* Hinkley Point *Arms et al.*
263 *UK* Bradwell *Vaughan et al.*
264 *UK* Berkeley *Ghalib et al.*
73 *UK* Redesigns of Calder *Cunningham*
1135 *France* EDF-I and EDF-II *Roux et al.*
48 *UK* Polyzonal fuel element *Ritz*
610 *UK* Hunterston element *Wootton, Dennis*
306 *UK* Testing fuel elements *Hardy*
1463 *UK* The HTGR experiment *Mitchell*
273 *UK* Steam cycles *Wootton et al.*
314 *UK* Possibilities of HTGR *Shepherd*
312 *UK* Advances in GCRs *Moore et al.*
246 *Switzerland* Sulzer BWR *de Haller et al.*
209 *Canada* NPD-II *Mackay*
135 *Sweden* R-III reactor *Margen*
559 *Norway* Halden reactor *Dahl*
421 *US* OMRE *Trilling*
1075 *US* Experience with power reactors *Roddis*
2462 *US* Shippingport *Simpson and Rickover*
1885 *US* Indian Point *Brower*
1923 *US* Operation of a BWR *Untermeyer et al.*
2372 *US* Dresden plant *Maxson*
2379 *US* Direct cycle BWR *Harrer*
1801 *US Belgian* BWR *Zinn et al.*
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2427 *US* Fermi reactor *Amorosi et al.*
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2027 *USSR* Russian programme *Emelyanov*
2139 *USSR* G-U reactor with nuc. superheating *Dollezhal et al.*
2183 *USSR* Boiling in 1st USSR stn. *Krassin et al.*
2184 *USSR* Russian PWR's *Skvortsov et al.*

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Reactor fuels and materials

Pioneering work on oxides and the new metals

IT IS NOT SURPRISING that the technical content of the papers presented to this second conference was not so overwhelmingly new as that at the first when only the most meagre information on the metallurgy of nuclear power had been declassified and made available in published literature. The interest of the metallurgist in this conference is therefore in the development and criticism of ideas already formulated and in the trends of reactor design as indicated by the emphasis on the materials being studied. In this latter connexion the most significant feature is, perhaps, the intensification of work on ceramic fuels, chiefly as uranium oxide, but not ignoring the possibilities of uranium carbide.

In the intervening period since the last conference a great deal of pioneering work has been done on the newer metals with low neutron capture cross-sections—chiefly zirconium, beryllium and niobium. There has, of course, also been a mass of research on the fissionable elements and much new data have been collected on the irradiation properties of uranium and uranium alloys: the problems of growth and swelling are now better understood phenomenologically but we are still awaiting satisfactory theories to explain the observations. This is possibly disappointing, especially to the academically minded metallurgist, but it is not surprising in view of the complexity of the materials and processes involved. It is clear, however, that irradiation effects in uranium have been sufficiently studied for the metallurgist to be able to prescribe for the control of harmful effects and to prolong irradiation life without fuel element failure.

BASIC METALLURGY AND CERAMICS

The papers chosen for presentation on basic studies did not seem to give a fully representative picture of effort throughout the world on the fundamental metallurgy within the field of nuclear power production. Those available at the time of writing (and this omits some Russian, French and American contributions) must give a very partial view of world activity on basic metallurgy.

Paper 1324 reports on Japanese work on nuclear fuels where thermal cycling and irradiation damage in uranium and the properties of ceramics have been studied. An attempt has been made to relate thermal cycling effects to internal friction characteristics of uranium metal and they have been able to show that dislocations formed by deformation during cooling (as a result of anisotropic thermal contractions and expansions) give rise to a low temperature internal friction peak. Reheating reduces the peak due to dislocation rearrangement by climb and absorption by vacancies. It is not clear what significance these observations have on thermal cycling behaviour.

An attempt has been made to combine the 'twin' and 'diffusion' theories of irradiation growth in which the internal stress produced by local twinning is relaxed by means of diffusion and precipitation of vacancies and interstitials produced by irradiation. A mechanism for this is discussed but none of these elaborations of the original ideas suggests a new critical experiment, and it is this sort of suggestion which is required for a new breakthrough in this field.

An interesting possibility in the ceramic field is evident in the investigation in Japan of dispersions of uranium silicide (USi_3) in molybdenum silicide ($MoSi_2$). Hot pressing at 1300° of 20 pc by volume of USi_3 in $MoSi_2$ produced a sample which is stable under oxidizing conditions because the molybdenum compound disposes itself around the uranium silicide in such a way as to prevent corrosion of the latter.

Plutonium alloys

There are two papers on plutonium in this section, 71 from the UK and 2197 from the USSR, both dealing inter alia, with several alloy systems. The Russian paper gives complete diagrams for no less than twelve binary systems and considers the tendency to form compounds or solid solutions from the point of view of the periodic table. A few limited generalizations can be made but it could not be expected that they would form the basis of a broad theory of alloying of the actinide elements. It is interesting to compare the conclusions of each group of workers: in general terms there is a remarkable degree of agreement in interpretation, especially bearing in mind the complexity of those systems where comparisons can be made. In one instance—plutonium-iron—Russian workers state that their diagram completely coincides with that of the British (there are a few differences in reported temperatures).

There is also approximate agreement in many features of the plutonium - uranium, plutonium - thorium and plutonium-zirconium systems which are all of potential technological importance. There are, of course, differences which will require much more laborious investigation for resolution but many inferences for technological design purposes will be possible with the diagrams in their present form. An interesting point of disagreement is to be found in the plutonium-aluminium system where the British workers report an extensive range (up to 12-14 atomic pc) of solid solubility of aluminium in delta-plutonium at room temperature. While agreeing approximately with the solu-

bility limits at high temperatures (~400°C), the Russians suggest a eutectoid reaction at 175°C leading to the formation of a compound Pu_3Al and alpha-plutonium. On this point the British workers report failure to produce an X-ray pattern for Pu_3Al which has been reported from the US.

A paper from the Indian Atomic Energy Establishment at Trombay (1705) describes experiments on the sintering of thorium and reports densities of 11·26 g/cc (theoretical 11·71 g/cc) for calcium-reduced metal. These high values are obtained by cold compacting at 40 tsi and sintering in vacuo at 1300°C of calcium reduced powder. The maximum density achieved is higher than that previously reported and it is shown that the sintered density is related to the bulk density of the powder, intermediate values of bulk density, and hence particle size, giving the highest sintered density. Assessment of the significance of these results is difficult because the paper does not give the number of specimens tested for each condition and does not indicate the reproducibility of the results.

PROPERTIES OF REACTOR MATERIALS

Developments in the technology of zirconium alloys in America are reported from Oak Ridge (1993) and procedures described for producing Zircaloy-2 in wrought form without preferred orientation and without anisotropy due to stringers elongated in the working direction. Intermetallic stringers are formed by precipitation from the beta phase which is usually elongated by rolling at a temperature where the alloy consists of two phases. At such a temperature the beta phase dissolves iron, nickel and chromium which are subsequently thrown out of solution from the beta phase on cooling. The precipitates are formed in stringers because of the elongated shape of the beta phase from which they originate.

This type of defect can be eliminated by the following sequence of operations: forge between 970 and 1050°C, roll to within 125 pc of final plate thickness between 500 and 785°C, beta-heat treat and quench, roll to finish gauge between 480 and 540°C and finally alpha anneal and quench. The difference between Zircaloy-2 fabricated by conventional commercial practice and the above procedure can be seen in figure 1.

The possibility of site welding of Zircaloy-2 has been increased by using an inert gas blanket on both sides of the weld. great care being taken to avoid turbulence. The chances of contamination are further reduced by a high freezing rate of the deposited metal achieved by careful edge preparation to give a small molten pool. This procedure is very effective with titanium and weld hardness can be kept below 220 dph. It is more difficult to keep the hardness to this value with Zircaloy but a considerable degree of toughness can be maintained.

Zirconium alloys

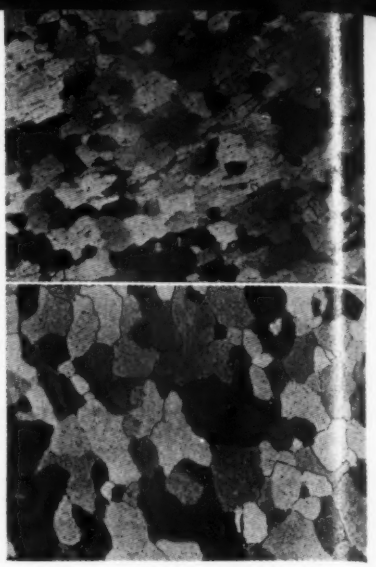
It is now well known that Zircaloy-2 is satisfactorily corrosion resistant in high pressure water and in uranyl sulphate solutions in the absence of irradiation. In the homogenous aqueous reactor the production of fission fragments at the metal surface sharply increases the rate of corrosion and Zircaloy-2 is not satisfactory under these circumstances. The rate of corrosion can however be considerably reduced by using a zirconium—15 pc niobium alloy. The difficulty with this alloy is the increase in hardness and loss of ductility which occurs on aging after beta-quenching. Hard and brittle structures would therefore be expected in multi-pass welds in such material. One transformation process in the zirconium-niobium alloys are complex but it has been found that decomposition can be delayed by ternary conditions of 2 pc palladium or 2 pc molybdenum. Although only cursory fabrication studies have been made on these alloys, the indications are that hot rolling at 800°C and extrusion at 950°C are feasible.

While these alloys have great interest for corrosion resistance, they show promise of a much wider structural use in reactors as they are the first zirconium alloys which can be heat treated to give high strength and yet are workable and weldable. The authors of this paper from Oak Ridge conclude that 'zirconium alloys are presently available with better neutron and corrosion properties than any other known reactor material of comparable strength and ductility.' This statement is, however, tempered by the remark that 'alloys which are less sensitive and more resistant to contamination in fabrication are urgently required to reduce the cost of preparing zirconium and titanium materials.'

Sheath failure

The corrosion of Zircaloy-2 in high pressure static water, in superheated steam and in loop conditions under irradiation has been studied extensively at Chalk River in Canada (194) where decision has been taken to build power reactors cooled and moderated with heavy water.

The now well-known phenomenon of 'breakaway' corrosion was found in static water at 360°C, the results agreeing well with those of other investigators. Post transition rates of



Microstructure of Zircaloy-2 plate (× 240). Above is specimen fabricated by conventional commercial practice showing preferred orientation and large intermetallic stringers. Work at ORNL developed a new work schedule giving the result below. This is a great improvement in all respects but has some small gas stringers formed during melting (Fig 1)

corrosion, i.e. rates after the onset of breakaway, were found to increase with temperature up to 450°C in superheated steam. Above this temperature the behaviour of Zircaloy-2 was strikingly affected by its heat treatment history. In wrought material or material which has been alpha-annealed an accelerated attack occurs above 450°C, leading to rapid disintegration of the sample. Because it is always accompanied by extensive hydride formation this phenomenon has been called 'hydriding attack.' In specimens which have undergone hydriding attack, three distinct layers in the film of corrosion product can be observed. A central layer, having a metallic appearance, has a composition roughly corresponding to $ZrH_{1\cdot5}$ while both of the outer layers are grey in colour and consist of monoclinic ZrO_2.

If the Zircaloy-2 is beta-heat treated hydriding attack does not occur and a normal thin oxide is formed on the surface and the specimen as a whole, contained a relatively small amount of hydrogen (430 ppm) which was uniformly distributed through the metal as a discontinuous phase (Fig 2).

The few sheath failures which have occurred in loop tests using UO_2 as fuel sheathed with Zircaloy-2 were characterized by heavy corrosion at the core-sheath interface and the sheath was heavily hydrided near the failure. In all of these instances there was no evidence of reaction with the UO_2 core. To explain this type of failure it is supposed that heat flow through the sheath is interrupted with

a consequent rise in temperature at this point, leading to hydriding attack. Because, under these circumstances, the temperature of the sheath is highest at the core interface, hydriding attack will occur from the inside and the pressure due to corrosion products deforms the outer part of the sheath and leads to failure in the embrittled material. Access of steam to the interface must be assumed for this mechanism to be operative. The characteristics of the failure are illustrated in figure 3.

Further work at Chalk River on aluminium alloy for pressure water conditions has revealed a marked difference in rates of corrosion under static and loop conditions. It was found that the ratio of corroding area of specimen to volume of water in the loop was very important and by increasing this area the rate of corrosion could be reduced from some sixty times that in static tests to about ten times this value. The corrosion proceeds by a 'spall and heal' mechanism but with large areas of sample the rate is much lower—this is attributed to the saturation of the water with dissolved corrosion products leading to the marked reduction in 'film dissolution.'

It is interesting to note that the most corrosion resistant alloys are complex ones containing several elements in small quantities—the best alloy in static water conditions consisted of the following percentage composition: 2 Ni, 0·5 Fe, 0·25 Si, 0·04 Be, 0·07 Zr and 0·2 Ti. The parallel here with Magnox is intriguing and possibly significant.

Work with aluminium

In Norway (767) development of aluminium alloys has a slightly different emphasis in that reactors there are being designed for lower operating temperatures in the range 20-150°C. Attention has therefore been given to a close study of the inter-related effects of iron and silicon as impurities in 2S aluminium. With less than 0·2 to 0·3 pc iron, grain boundary attack occurs and if silicon is present more iron is required to prevent this. It is concluded that alloying constituents impart their beneficial effects on corrosion by virtue of the current set up between the aluminium anode and the cathodic phases formed by the alloying elements.

The intention to increase the operating temperature of Calder Hall type reactors (as the Advanced Gas Cooled Reactor) has led to the investigation at Harwell of the corrosion resistance of beryllium in carbon dioxide (319). In wet carbon dioxide breaking corrosion begins after 400 hours at 600°C but in dry gas the onset of rapid corrosion does not occur below 650°C. It seems therefore that the corrosion resistance of beryllium is not likely to place a limit on the life of a fuel element if the temperature of the sheath does not exceed 600°C and if the moisture content of the gas is controlled at a low level.

Beryllium fabrication problems

A major difficulty with beryllium as a sheathing material is with welding and various 'integral' canning methods have been investigated to avoid joining by fusion. Forging of a sheathed composite unit of a metallic uranium core surrounded by a tamped layer of beryllium powder has proved successful. Forging of the composite element in dies at pressures of 50 tsi and at 1000°C are necessary. It is also essential to control very carefully the shape of the uranium and the shape of the mild steel sheath if irregularities in the final thickness of the beryllium are to be avoided. A cross-section of a typical element made by this method is shown in figure 4.

In view of the care necessary for obtaining correct shapes for sheath-forging, co-extrusion would appear to be a more satisfactory method of fabrication. For this a blind hole is drilled in a cylinder of beryllium, the uranium fuel inserted, the hole closed by a plug and the composite unit extruded at about 500°C. Reductions in area of only 2:1 are required to seal the end of the can while uniformity of core shape is achieved by using beta-quenched fine-grained uranium. Thermal cycling in the alpha-range for 1000 cycles (50-620°C) has been withstood by both types of element in spite of considerable increases in thickness or diameter (5 to 10 pc) due to change in shape of the uranium.

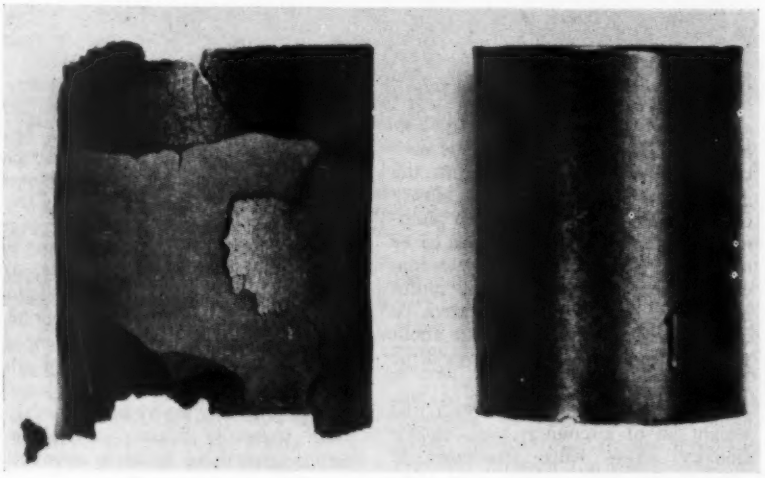
The co-extruded elements have withstood 200 cycles through the alpha-beta charge and have also been irradiated to 300 MWd/t at 250°C without failure.

IRRADIATION EFFECTS

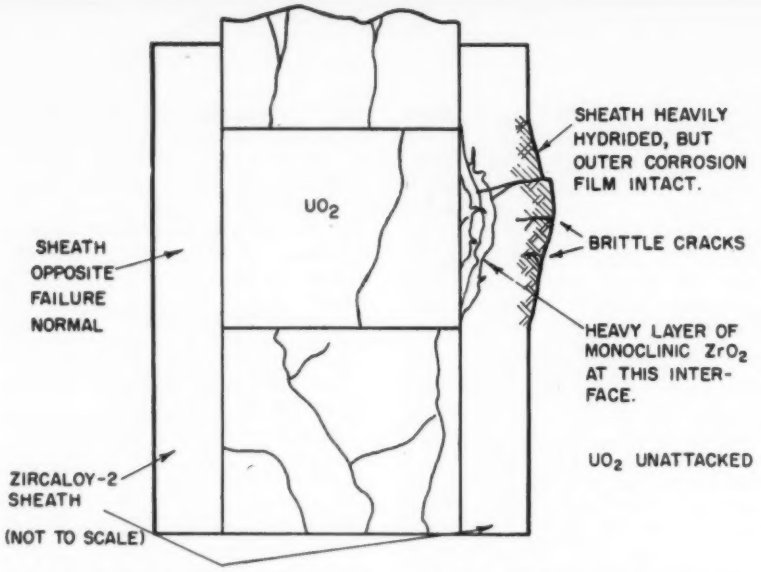
The Argonne National Laboratory of the US have completed further extensive work (1890) on the growth properties of uranium.

Growth coefficients have been derived for alpha-uranium in a variety of metallurgical conditions but the general picture remains unchanged i.e. maximum growth occurs in material rolled at 300°C to produce a large component of (010) poles parallel to the rolling direction; randomizing by beta-quenching reduces the growth coefficient nearly to zero: small growth coefficients are also obtained by rolling at 600°C. Much of this careful and accurate work seems to be diminished in value by the absence of indications of the specimen temperatures although these are clearly in the growth range and presumably much below 400°C. Furthermore the growth coefficients are almost certainly temperature dependent. A feature of this work is the high irradiation doses to which the specimens have been subjected—as much as 1·75 atom pc in some cases.

In investigating powder compacts the effect of temperature has been considered and the incidence of swelling is clearly and accurately indicated. Up to 450°C density changes of less than 5 pc per atom pc burnup are observed but above this temperature large density changes occur and at 500°C they



Tests at Chalk River on Zircaloy-2 tubing show (left) alpha-annealed and (right) beta-quenched specimens after 24 hours in 540°C, 100 atm. steam (×2·2) (Fig 2)



Failure of Zircaloy-canned oxide fuel element is believed due to an interruption of heat flow through the sheath causing hydriding attack at the inner surface. (Fig 3)

are as high as 25 pc decrease in density per atom pc burn-up. Metallographic examination shows that the density decrease is usually due to a large central void and a surrounding zone of fine porosity—it is considered that the large void is the result of an effective inward movement and coalescence of the already nucleated bubbles of fission product gases.

Several dilute alloys of uranium have been irradiated with unexpected results in some instances. For example, a 2·5 pc molybdenum alloy with uranium had a five times larger growth coefficient when quenched from the gamma-phase than when slowly cooled. The growth of extruded plutonium-uranium alloys was found to be markedly dependent on plutonium content—an alloy with 14 pc plutonium elongated 96 pc at 0·4 atom pc burnup, whereas an alloy with about 18 pc plutonium elongated only 8 pc under the same conditions.

Zirconium-uranium alloys with 1·62 weight pc of zirconium were dimensionally stable when irradiated at 350° but at 600°C there were large volume increases.

Interest in the ternary alloy with 5 pc zirconium and 1·5 pc niobium has been shown because this alloy resists aqueous corrosion in the gamma-quenched condition. In the swaged condition this alloy has a fairly high growth coefficient during irradiation but, after gamma-quenching, the coefficient is doubled. Growth can be reduced by factors as high as sixty times by certain isothermal heat treatments: it is not clear what effect these have on corrosion resistance, but it is probably deleterious. These disappointing results are not made better by the finding that even the gamma-quenched alloy loses its corrosion resistance after only 0·07 atom pc burnup, presumably due to an irradiation-induced change in metallurgical structure.

Uranium-fissium alloys

An interesting group of experiments was made on the so-called uranium-fissium alloys which contain molybdenum, zirconium, ruthenium, rhodium and palladium in the proportions in which these elements remain after pyrometallurgical processing of irradiated fuel elements. Here again heat treatment very strikingly influences irradiation growth behaviour. Swaged alloys quenched from the gamma (but not retaining gamma) grow appreciably but isothermal transformation of the same alloys reduces growth almost to zero. By contrast another alloy, with more fissium, which retained gamma on quenching had a comparable growth stability only in the quenched condition.

Addition of molybdenum above those found in fissium causes irradiation growth to become essentially independent of prior heat treatment.

The contribution on irradiation damage from the Windscale laboratories in the UK (50) gives additional data on irradiation growth of uranium obtained from examination of a large number of fuel elements taken from the plutonium-producing reactors. A statistical method of assessing wrinkling in irradiated uranium bars shows that surface roughening decreases as the irradiation temperature increases above about 150°C and is probably absent above 400°C. Although the evidence is very sparse the investigators draw their curves to show a decrease in wrinkling below 150°C and therefore conclude that the phenomenon is at its worst at this temperature. Density determinations show that there is a decrease of 0·7 pc for a mean irradiation level of 1000 MWd/t and a mean temperature of 220°C. Density decrease is temperature dependent and, as would be expected, is at a maximum in the region of greatest growth (or wrinkling) between 150° and 200°C. Metallographic examination revealed small irregular holes between 10^{-2} and 10^{-4} sq. mm. in cross-section in sufficient number to account for the density decrease. The holes are not, in general, located at grain boundaries but are frequently associated with inclusions especially those in the form of flakes or stringers. This type of porosity is said to be quite distinct from that associated with swelling.

Irradiation creep

The much publicized phenomenon of irradiation creep has been investigated at Windscale particularly in relation to the performance of the Calder Hall reactors. The effect was found to be much as had been predicted by the early experiments and quantitative predictions could be made. These led to the alarming conclusion that, in the worst position in the reactor, a fuel element with an initial bow of 0·025 inch, would develop a bow of 1 inch for an irradiation of approximately 550 MWd/t. Remedial measures were obviously required and lateral braces of magnesium alloy in the middle of the fuel element have been found to restrict bowing satisfactorily at the irradiation doses so far experienced. It is very encouraging to note that only 13 fuel elements have failed from about 30,000 inserted and most of these failures can be directly attributed to manufacturing faults such as defective welds.

American work on the effects of irradiation on the properties of structural materials was presented to this section of the conference in a comprehensive review paper (1978). It is now well established that the yield point in steels is increased by irradiation and the recent work has added some detail to this observation. At low irradiation temperatures and doses the yield stress increases but the upper yield becomes less prominent and, as the dose increases, the yield point elongation is lost. At high doses between 10^{19} and 10^{20} neutrons per sq. cm all resemblance to the typical yield point in mild steels is lost and characteristics are assumed which are similar to the irradiation-induced yield points in face-centred cubic metals.

The important engineering property of impact strength has received much attention in the US, as in this country,

and shifts in the transition temperature of as much as 220°C have been observed. At the high temperature end of the notch-impact/temperature curves the loss of energy absorption seldom exceeds 60 pc and a shift in transition temperature is noted before there is an appreciable reduction in energy absorption. These phenomena are, not surprisingly, temperature-dependent and the changes induced at irradiation temperatures of about 300 to 350°C are less than at temperatures of about 95°C. However, at the higher temperatures the change in energy absorption due to irradiation is very temperature sensitive.

From the practical point of view this work leads to the conclusions that carbon steels are less variable than some alloy steels in their response to irradiation; that it is an advantage to keep the carbon content above 0·2 pc; and that the steel should be processed to give as low a transition temperature as possible since there is no evidence that a steel with a low initial transformation temperature will undergo a greater increase than one with a higher initial value.

Engineering properties

A further subject of engineering design interest is the irradiation-induced yielding of face-centred cubic metals and the associated effects on other mechanical properties. The load-strain characteristics of irradiated face cubic metals are (a), more plastic deformation occurs than in iron before an upper yield is reached (b) the drop in load after yield is abrupt and (c) there is evidence of work hardening following yielding. Further, after doses of 10^{20} n/cm² the uniform elongation is reduced without a corresponding change in reduction in area. This is very important from the design point of view and more work will be necessary to determine the temperature dependence of the effect since, at reactor operating temperatures, it might not be so severe as the present experiments suggest.

The British work (80) on the engineering properties of steels under irradiation has shown that the transition temperature is generally increased when the exposure exceeds about 10^{19} neutrons per sq. cm. The largest change in transition temperature that is reported is about 70°C; this does not occur at the maximum irradiation dose but at $5{\cdot}7.10^{19}$ n/cm². At $9{\cdot}3.10^{19}$ n/cm² the increase in transition temperature is some 10°C less and the curve has a peculiar double transition. The experimental points on each curve in this series are quite self-consistent and it appears that there is a real anomaly here awaiting explanation. It is interesting to note that completely ductile fractures were not obtained until the second step in the transition curve was reached at a temperature about 40°C higher than that of the 'maximum increase' referred to above.

A cautionary note in the American paper is timely and important in maintaining a balanced practical perspective:

One of the greatest uncertainties in applying irradiation effects data to reactor components is the measurement and calculation of the effectiveness of the fast neuron flux. Fast neutron fluxes are neither commonly nor easily measured in test reactors, and the calculation of the fast flux distribution in power reactors is apparently subject to large errors. Furthermore, there does not seem to be a sound basis for comparing the effectiveness of different fluxes of fast neutrons where two different neutron spectra are involved.

Harwell tests on beryllium-canned uranium under thermal cycling conditions are promising. This radiograph shows a typical specimen which can consistently withstand 1000 cycles from 50–620°C without failure. (Fig 4)

FABRICATION OF FUELS

A contribution from France (1157) considered the problems of elements for pressurized gas reactors of the plutonium and power producing types. It is interesting to note the similarity of the British and French approaches to the problem and the almost identical conclusions reached for future development. With regard to sheathing, magnesium was chosen for operating temperatures of about 400°C but the Magnox-type alloy (used in Calder Hall) is rejected in favour of magnesium—0·6 pc zirconium. Welding presents no problem with this alloy and there is no chance of combustion in carbon dioxide at temperatures below 750°C. For the fuel, casting in vacuum and extrusion in the upper alpha-phase region have been investigated but, as in the UK, casting is preferred. For the future it is concluded that economic power plants should operate at sheath temperatures between 500° and 650°C and a minimum irradiation of 3000 MWd/t must be obtained. Beryllium sheathing with UO_2 fuel gives the most promise of achieving these conditions and the French authors go further in suggesting that such fuel elements should make it possible to avoid the steam cycle by using the hot gas from the reactor core to operate a gas turbine (c.f. the high-temperature gas cooled reactor of the UK programme).

Among the other types of fuel element whose manufacture is described is the element for the UK Dounreay fast reactor (44). An important feature of these fuel elements is the embodiment of a safety device to enable the uranium to be removed from the core in a controlled fashion in the event of a power excursion which might otherwise increase the criticality of the assembly. For this, the fuel is contained as an annulus between inner and outer metal tubes selected so that the inner would fail at a lower temperature and more rapidly than the outer due to reaction between the metal sheath and the uranium fuel—a reaction which would take place due to temperature rise in the fuel following an accidental increase of power. The controlled release of molten uranium through the inner tubes of the fuel elements would lead to a decrease in criticality. The basis of this device is clearly metallurgical compatibility between fuel and sheath. Niobium, tantalum and molybdenum were possble metals for the outer can and niobium was chosen because it had the best combination of the important properties of ease of fabrication and welding, ductility and the formed metal and loss neutron absorption. For the inner tube, choice was more limited and of the elemental metals vanadium was the only possibility. Due to the uncertainty of the availability of vanadium a composite tube of tantalum-coated nickel was developed to satisfy the correct res-

ponse to attack by uranium at high temperature. This alternative has now been abandoned since the supply of vanadium to a suitable specification has been assured.

For the fuel, although powder metallurgy methods were investigated because of their promise of high economy in expensive enriched uranium, vacuum casting was chosen. This choice was further favoured because of the decision to use an alloy fuel containing ½ pc chromium which could much more easily be made by melting than by powder techniques. Casting to final size on all dimensions of the tubular fuel units was not feasible because of the high rejection rate. Machining 'all over' produced a high acceptance rate of components but was likely to be uneconomical because of the high cost of recycling swarf. The method adopted for further development was consequently a combination of casting to size and machining in which the bore of the tube was cast to size and used as a reference for machining of the outside surface.

The problems here described in a few hundred words are put into perspective by a statement in the paper that 'the development of the fast reactor fuel elements has called for a consistent scientific effort measured in tens of thousands of man days per year over a number of years, and an expenditure of hundreds of thousands of pounds.'

Enrico Fermi fuel elements

The immense task of designing and making a fuel element is also reflected in the comparable description of the US development of the elements for the Enrico Fermi sodium-cooled fast neutron breeder reactor designed to give 300 megawatts of heat (792). The development period has been devoted to three distinct phases, the end of each being prompted by a radical change of ideas of metallurgical feasibility. In phase one it was the intention to bond the fuel to the sheath by a 'casting-in' process in which the molten uranium is poured into the sheath tube which acts as a mould. The eutectic uranium-chromium alloy (5 wt. pc chromium) was successfully cast into low carbon iron tubes with oxidized surfaces and into reactor grade zirconium but the bonding was unacceptable from the heat transfer point of view. More successful bonds could be made with uranium—2 pc zirconium alloys cast into zirconium but the casting procedures were considered to impose undesirable restrictions. Sodium filling of the interstices where the bonds were poor proved to be successful in various combinations of fuel and sheath but the possibility of fission product gases accumulating at these points causing local heating and failure was taken to be too great a risk.

In the second phase co-extrusion of uranium—2 pc zirconium alloys in zirconium sheaths with integral end-capping was developed on a laboratory basis. The undesirable textures in the fuel could be removed by melting of the fuel within its sheath by zone-melting techniques. Irradiation characteristics of the fuel were still thought to be unsatisfactory.

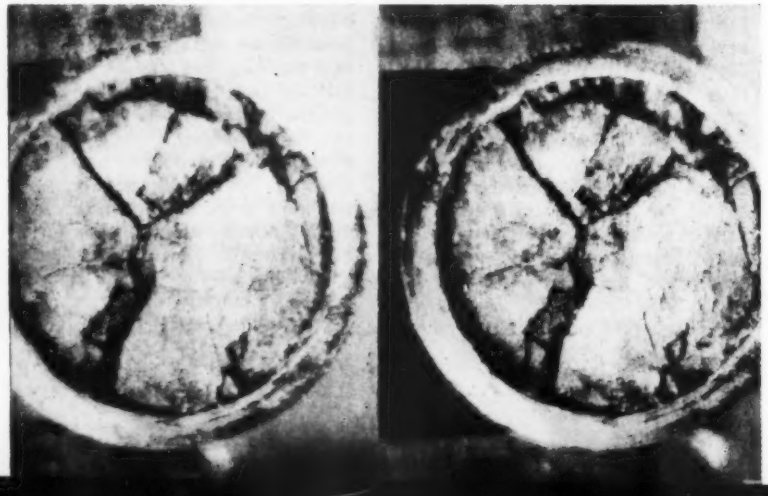
In phase three, irradiation stability of the fuel was given priority and uranium—10 wt. pc molybdenum alloys have been used. The element is fabricated by co-extrusion of an assembly consisting of the fuel alloy billet, the zirconium sheathing material and an outer container of steel which prevents oxidization of the zirconium and sticking to the extrusion dies.

The contrasts with the British fuel elements are in the method of fabrication and in the choice of alloy—the statement in the American paper that 'it had been determined that no known low percentage alloy addition to uranium was completely acceptable for a fast reactor core element' is probably most significant in reflecting the relative abundance of enriched uranium in the two countries.

Advantages of uranium dioxide

Many of the papers at the conference underline the difficulties of dealing with metallic uranium and its alloys in fabrication, heat treatment and especially in service conditions in a reactor. It is not surprising therefore that there is an intense search for alternative forms of fuel and, at the present time, uranium dioxide seems to have many advantages for this purpose. It has been extensively investigated at Chalk River (193) in a series of irradiation tests which lead to the encouraging and unequivocal conclusion that 'uranium oxide is thoroughly satisfactory in fuel elements cooled with pressurized water.' However this statement needs to be somewhat qualified because the low thermal conductivity of the oxide limits the heat rating for a specified maximum temperature in any given fuel element. The need for low fuelling costs makes it desirable for the fuel to be in massive form and it follows that there is a real incentive to determine the maximum heat ratings which can be safely attained. Although it has been considered on intuitive grounds that the maximum fuel temperature should not exceed the melting point of the oxide the need for this has not been demonstrated—heat ratings based on this criterion might therefore be exceeded if a molten core could be shown to be safe and otherwise satisfactory. On irradiation, uranium oxide bodies develop radial cracks, persumably due to thermal stressing, but they do not seem to interfere with performance.

Results of cold-swaged uranium dioxide elements irradiated in a pressure water loop at Chalk River show radial cracks which do not however seem to affect performance. (Fig 5)



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Seated round NP's microphone in a broadcasting studio at the Palais des Nations is our team. They are (l. to r.):

BILL DAVIDSON Editor, *Nuclear Power*

HOWARD GOTT Nuclear plant design engineer, *Central Electricity Generating Board*

PETER GRANT Head, Reactor Physics Section, *The General Electric Co Ltd*

WALTER H. ZINN President, *General Nuclear Engineering Corp, Dunedin, Florida*

R. N. MILLAR General Manager, *Fraser & Chalmers Engineering Works, The General Electric Co Ltd*

There's a good future for gas cooling

US-UK team agree in Geneva tape discussion

While so many experts were gathered in one place, we thought it a good idea to get just a few of them to talk around this subject. So we invited Walter Zinn, former Director of Argonne National Laboratory, whose own company is actively engaged in gas cooling developments to meet some of those working on this side of the Atlantic. Here's what we recorded.

Davidson: Most of us were at the session this morning, when Mr Allardyce of the World Bank, talked about the SENN project. From his analysis it looks as if there's very little to choose on the total overall cost of units between the gas-cooled and the water-cooled type of reactor. Dr Zinn, perhaps you would give us your view on the present state of gas cooling and indicate how you think we might get it better.

Zinn: Well, you will recall Mr Allardyce also indicated that the capital cost of electricity from these reactors would be some ten or fifteen per cent more than the cost from conventional power in Italy. Now from the point of view of someone in the United States, this would be not ten or fifteen per cent; it would be a hundred per cent, because our conventional generating costs are lower.

So we are mainly interested in the potential of any of these reactors for future improvement and I share the opinion of many people connected with gas cooling in Britain that the gas-cooled reactor has a substantial potential for improvement.

Davidson: Can you give us any idea on how this could be achieved?

Zinn: There isn't any one item that you can select and say just do this and you have realized the improvement. We all agree I believe that it will take improvement at quite a few points. But I think there is general agreement on one, namely, that the temperature of the gas coming out of the reactor must go up. We want higher temperatures, that's just one point. One can quickly name others and then quickly I believe get into an area of some conjecture or difference of opinion. For instance, some will say raise the temperature but stick with the graphite system and I think that we all realize that to do this will take enriched uranium—at least to raise it a very considerable amount. Other people, and I think I am one of them, would like to see the temperature go up but would like also to see the enrichment held down and if possible kept as natural uranium.

Davidson: Perhaps Mr Millar could say something on that because his company I know are feeling much the same way.

Millar: Yes, I agree with Dr Zinn that it is desirable to increase gas temperature, but I think one has to bear in mind that complexities in even the more conventional part of the reactor may result from increases in gas temperature—in other words, an increase in thermal efficiency resulting from increased gas temperature may be offset by some of the complexities or difficulties in designing ducts and other systems to handle high gas temperatures. However I think there is a more fundamental consideration. The gas-cooled reactor is really the only reactor which can be designed to suit the economy of any particular country. It can be built to use natural uranium with a high capital cost and a low power cost, or it can be used with enriched fuel and lower capital cost. Now conditions vary in every country; underdeveloped countries where capital is difficult to obtain may be forced to go for a low initial capital cost at the expense of the power cost. More developed countries such as the United Kingdom may be more concerned with a low power cost than a low capital cost. And I think while it's true to say that there are certain objections in the design of these reactors one can't define them without defining

the particular countries in which one is considering the reactor installation.

Gott: I think that the question of increasing the temperature by itself is not enough to give us the decrease in capital cost that we're looking for. At the moment we're getting efficiencies of something like 27-28 pc. You can put these up by higher gas temperatures, but even if you took 40 pc which would be quite ambitious, this is a relatively small improvement. It's also necessary to do something to increase the rating and I think we may very well be right on the edge at the moment of permissible ratings with the Magnox canned reactors that we're using in the UK. This may be at least as provocative a reason for a change in type as a desire for increase in temperature.

Zinn: The framework in which I think of reactors is of course the United States, where we've got to get a low capital cost and also, of course, low operating cost. I agree very much that temperature alone won't do it, but it's the most direct gain—raising the efficiency. And then I agree that the rating—we call it the specific power—of the machine must come up. And very considerably, before we can get a machine that will qualify under capital cost.

Grant: Well I think I could back that up because at the present time with metallic uranium one of the serious limitations is the maximum temperature in the fuel rod. In order to increase the specific power one is clearly going to have to make the rod much thinner or use a multiple rod, and this will lead you

Zinn

Temperature alone won't do it — ratings must come up too

directly to enriched fuel. At that stage it seems to be more sensible to take a rather large jump and go to the use of ceramic fuels, where you can get a higher power density and a higher temperature at the same time. Your fuel cost may go up somewhat—it depends, I think, on the burnup that can be achieved with the oxide fuel, but bearing in mind that at the present time roughly two-thirds of the power cost is due to capital charges and one-third fuel, there is an out-of-balance situation and one could really afford to put the running cost up provided you do in fact put the specific power up at the same time.

Gott: Yes, provided that in doing this you don't completely rule out the possibility of running on a peak-load basis, because in that stage of our development in the United Kingdom we are very interested in reactors of a much lower power level.

Millar: Nevertheless I think there's still going to be a demand during the next few years for large base-load reactors in Europe and I think we shouldn't lose sight of the point which Dr Zinn raised that there is merit in retaining a system which operates on natural uranium. Both economically and from the political economy of the countries investing in this type of plant, there's much to be said for independence of external sources of fuel—enriched fuel—and furthermore the use in due course of plutonium, which can be produced in these reactors for enriched systems in these countries at a later date.

Davidson: In the last issue of NUCLEAR POWER you may have seen an article by Mr Yasukawa of Japan on why he chose this type of reactor for his first power scheme and this was a point he made—the Japanese want eventually to do their own fuel.

Zinn: I would say aside from that, even in a country where the incentive to stay away from enriched uranium doesn't exist, such as the United States, we are pressed very hard to get a fuel cost that is comparable with our coal cost, and if you can get the rating in the natural fuel—*if* you can get the rating—then we like as little enrichment as possible because enrichment costs money and everything connected with enrichment costs money. Even fuel processing costs more when the enrichment is high. So we have given serious consideration to dropping the graphite as a moderator and trying heavy water—you get more reactivity that way—and we are seriously working on the design of a machine which in large sizes could be natural-uranium-fuelled and gas-cooled, provided our hopes are borne out by results—experimental results—in getting the rating. We can't afford heavy water with a low rated machine, that's as obvious as anything.

Millar: This would use ceramic oxide elements?

Zinn: We see no future for us in metallic elements because to get the rating up we clearly also run into temperature problems. And along with getting the rating up we also need a longer fuel burnup and this we can't get either with metallic fuel. Unless someone discovers some way of alloying an innocuous material with uranium metal which will strengthen it so it can take the irradiation—no one's got near doing this yet.

Gott: There doesn't seem very much prospect of it. It's hoping for a miracle this.

Millar: Don't you feel, Dr Zinn, that there are some very serious engineering problems in the heavy water-moderated gas-cooled reactor?

Zinn: Yes, we are trying to solve them. I agree.

Gott

As far as we can get with Magnox

Millar: I would look on it, perhaps irreverently, as a physicist's reactor and not an engineer's reactor.

Zinn: Well, we think the thing that would make it practical would be a development of a suitable pressure tube, and we believe we are making some good progress along that line.

Davidson: The fourth annual report of the UK Atomic Energy Authority states that the British are working on this type of concept and they mention specifically the problem of header design. Do you find this too, Dr Zinn?

Zinn: Yes, we have been working on header design. We now have shop work going on mock-ups. It will require development of special techniques of assembly because the header design is really difficult. You take something from room temperature to a thousand degrees F and it's big and it wants to expand in lots of different ways, and it's a difficulty, the design. The headers of course have to be big if it's gas. But I don't think it's insoluble. We are relatively optimistic. Maybe we'll be disappointed, but we won't accept defeat on the matter until we've made quite a few tests and we're just barely starting them.

Davidson: Mr Gott, does the Electricity Board have any views on the idea of heavy water moderation?

Gott: I think it would be very difficult in the United Kingdom to develop a heavy-water-moderated gas-cooled reactor so that any of the generating boards could have one in service by 1965. It's just a question of straight design and development time. I imagine that when the thing is there and something to look at then you can think about buying it.

Millar: There are presumably developments which will lead to substantial reductions in the cost of heavy water which may well make the reactor more attractive.

Zinn: We don't find, with the highly rated reactor, that the penalty for heavy water is very great. It amounts to perhaps 4 mill/kWh, but it's made up easily by the longer burnup we can get. Now we believe that the ceramic fuel, but not necessarily the jackets—we don't know the jackets yet for this reactor—the ceramic fuel, the oxide, will give us a longer burnup. We're pretty sure of that. So we think the cost of the heavy water or the penalty due to heavy water is not intolerable.

Davidson: You're all aware of Dr Lewis's plans in Canada for his NPD-II where he claims very high burnups for his ceramic element. It's heavy water *cooled* of course. Would this experience of Dr Lewis's be relevant to a gas-cooled heavy-water system?

Zinn: Well there are two points which are common. Both reactors would need a pressure tube and both use oxide fuels. But I don't agree with you that he's specifying a terribly high burnup for ceramics. He's talking about 8000 to 10,000 megawatt days per ton and that as an average burnup for a tube reactor in which the fuel can be shuffled. That's not exceptional contrasted with what we need in our pressurized or boiling water reactors. We get an *average* of 10,000 megawatt days per ton, and some elements go to 18,000.

Grant: Even on the present types of uranium fuels in the graphite-moderated reactor, the limitation on burnup now is a metallurgist's problem and not the

Grant

Axial and radial shuffling will be needed

physicist's. If there were no problems of swelling and this sort of thing with the fuel elements we could easily get 5000-6000 MWd/t from natural uranium in a graphite-moderated reactor. This would involve a fairly elaborate shuffling system. In addition to the axial shuffling which is now being done one would have to do a certain amount of radial shuffling, but this doesn't necessarily involve any more movement in the charge machine. So that certainly Lewis is being very conservative in his present burnup requirements.

Gott: You'd be limited by radiation damage to the fuel or by the reactivity considerations?

Zinn: Our calculations and large critical experiments in heavy water indicate that with gas cooling and heavy water moderation we can anticipate a fuel life of about 6000 MWd/t with what we call the fuel push-through method, which is not quite as elaborate shuffling as it could be. This is not quite as good as we would like to see and we are looking at ways in which we might improve it a little bit.

Millar: This is a limitation imposed by reactivity considerations and not by fission product gases?

Zinn: It's due entirely to reactivity and when I said earlier we don't yet have a jacket, I had in mind that as you go to higher temperature in your ceramic fuel —higher than we use in the water reactor—your jackets have a little harder job to do.

Millar: You wouldn't accept the philosophy of having an active circuit?

Zinn: *I* might accept it, but I don't know that I'm a good enough salesman at the moment to sell it to the American utility operators. They have sort of shudders when they look at a large system—which a gas system would always be—containing any sizeable amount of fission product activity.

Millar: Our approach has been on the same lines. We feel that under no circumstances should one accept an active primary circuit if this can be avoided.

Zinn: I made one remark there that I hoped I would get agreement on. I think that a slightly or a partially radioactive system is the worst of two possible worlds—in other words, jackets which leak *some* but aren't really tight. You've either got to take the jackets off and take all the fission products—I'd go the whole way if I go at all. Otherwise I'd say with you we must have really good jackets and good detection systems.

Davidson: Have you, Dr Zinn, had an opportunity of studying the two British papers on what we call the advanced gas-cooled reactor and the high temperature gas-cooled reactor?

Zinn: I have looked at the papers, but study them I haven't had a chance. They look very interesting. Many of the thoughts expressed there are ones I must confess we have had too.

Davidson: Perhaps Mr Millar could maybe say something about those because his company are known to be interested in the high temperature one anyway.

Millar: Yes, I don't think the paper on the high temperature gas-cooled reactor in any way exaggerated the potential of this reactor. There seems to be a slight tendency to cool off on this particular reactor, but I think personally that it has a very great future. It is dependent on advances in certain metallurgical techniques, particularly in the production of impermeable carbon, but there's no reason why these should not be achieved on the time scale under which this reactor is being considered.

Zinn: May I ask where impermeable carbon is used?

Millar: In the fuel element.

Zinn: Oh, it's used as the jacket!—a ceramic jacket. Our project is proposing to invest very sizeable sums of money in that type of development. We have three

Millar

Impermeable carbon may be the answer

jackets that we wish to develop for this purpose. One is stainless steel—obviously requiring enrichment. It sounds easy but when you get down to the details with the stainless steel jacket for high temperatures it's not so easy. Beryllium we would like, in order to get the enrichment down to the natural, but it isn't easy because in most designs which are liked we also need fins on the jacket. What we would really like to see is the ceramic jacket, but impermeable to fission products—when you have it let us know!

Millar: On our stand at the exhibition you can see such material.

Zinn: I will take the opportunity to visit it. I haven't been there yet, but I'll be looking.

Davidson: At one time for the HTGR it was proposed to let the primary circuit become contaminated and have a continuous clean-up system.

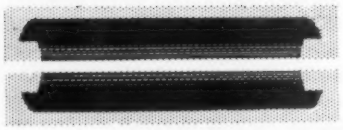
Millar: The original scheme was to bleed off gas from inside the fuel element and allow clean gas to leak in. But this wouldn't of course prevent the circuit from becoming active by back diffusion.

Zinn: It also limits your fuel shuffling, because you make now a long fuel element that goes all the way through the reactor and now you're back where we started.

Grant: As long as you're aiming to keep the enrichment down, then I think your aim must be to do fuel shuffling, because then you get the benefit of the new fuel.

Zinn: And of course with that comes the engineering of a very complicated and difficult unloading and fuel handling machine. There are still lots of opportunities for mechanical engineers to be ingenious.

Millar: A lot of opportunity for them to be too ingenious.



GENEVA 58

by A. E. ROBSON, Ph.D.
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Controlled Thermonuclear Fusion

—many machines but answer still elusive

THE COMMON objective of all thermonuclear work has been to achieve a reaction in deuterium or deuterium-tritium mixture. This is a system in which fusion reactions are produced by random thermal collisions in a very hot gas, and it seems at present that this is the only way in which the fusion energy could, in principle, be made to exceed the energy which must be supplied to the systems in order to produce the reactions. This is of course an essential condition if useful power is to be obtained.

At such high temperatures all matter is in the state of plasma; that is, an equal concentration of free electrons and positive ions. Even if particle and heat conduction losses could be suppressed, an unavoidable radiation loss will occur due to *Bremmsstrahlung* emitted by the electrons in collisions with the positive ions, and this sets the minimum temperature at which the reaction can 'break-even.' This turns out to be about 40 million degrees Kelvin for the D-T reaction and about 200 million degrees for the D-D reaction. In a power-producing fusion reactor, temperatures of the order 10^9 °K are envisaged. Although the D-T reaction is the easier to produce, the D-D reaction is the more desirable, as deuterium occurs naturally whereas tritium does not.

The achievement of very high temperatures is not the only problem. To produce power densities comparable with those in fission reactors, the plasma density must be about 10^{14}-10^{15} particles/cm^3; at 10^9°K this represents a pressure of about 10^2-10^3 atmospheres, which poses difficult problems of containment. Furthermore there is a minimum time for which the plasma must be contained, so that the fusion energy can pay back the energy expanded in the initial heating to reacting temperature. This time is about 0·1 sec for the D-T reaction, and several seconds for the D-D.

Whether the threefold objectives of temperature, density and time can in fact be achieved, and if so by what method, is still uncertain.

All the principal proposals had the common feature that they employed magnetic fields to confine the plasma and keep it away from the walls of the container. Magnetic confinement is effective because the plasma particles move in tight spirals about the lines of force, and can only move across the field if they make collisions which allow them to change from one line of force to another. The higher the temperature, the less frequent the collisions and the more strongly the plasma is 'tied' to the lines of force. Motion along the field is still possible, but motion perpendicular to it is greatly reduced. The plasma pressure is then supported by the 'magnetic pressure,' and in this way pressures of hundreds of atmospheres can in principle be contained by fields of practically realizable size.

The pinch effect

Historically the first, and subsequently the most investigated, approach is the pinch effect. When a strong current is passed through a plasma, the attraction between parallel current elements causes the plasma to contract towards the axis until the outward pressure of the plasma balances the attraction of the current elements. The plasma pressure is then supported by magnetic pressure. In the steady state the simple relation—$I^2 = 4NkT$—describes the plasma kinetic energy which can be contained; here I is the current, N the number of ions/cm length of the current channel, and T the mean temperature of the plasma. The degree of pinch does not appear in the relation, and is determined by energy balance considerations. It would seem therefore that by choosing N, any desired temperature could be reached by passing sufficiently large current.

This was the simple picture which inspired the early work on the pinch effect. The first experiments were started independently by Sir George Thomson and by Dr Peter Thonemann in Great Britain, and extensive investigations have since been carried out in Britain (78), America and Russia (2298). In all cases the practical approach has been to work up through stages of increasing size of apparatus passing larger and larger currents through rarefied deuterium gas. The experiments have been carried out in straight and toroidal tubes; whereas the former have the advantage of simplicity, they have the disadvantage that electrodes are necessary and these may have a cooling effect on the plasma and introduce undesirable impurities into the discharge. The torus has the advantage that it offers a completely closed, electrodeless magnetic bottle, but it suffers from the complication of having to be made the secondary turn of a transformer in order to induce currents in it. In both cases, high currents are obtained by charging up banks of condensers and discharging them rapidly into the apparatus.

The main stumbling-block of the pinch programmes is the instability of the simple pinched discharge. It was soon discovered that as currents exceeded a few thousand amperes, the pinched channel developed violent 'kink' and 'sausage' instabilities which destroyed its cylindrical symmetry. The plasma was brought into contact with the walls of the apparatus, and attempts to reach high temperatures were thereby frustrated.

The pinch projects can be divided into two main streams. The 'fast' pinch approach originally set out to create discharges which reached peak current before the instabilities had time to develop. The quasi-static pinch

approach tried to obtain long duration discharges which were stabilized by external means.

The fast pinch has been studied extensively at Berkeley (2170), Livermore (1064) and Los Alamos (1860) (USA,) in Russia (2301), and more recently at AWRE, Aldermaston (1460). In most cases the experiments have been performed in straight tubes, and currents of the order 10^5-10^6 amperes have been established in a few microseconds. At such rapid rates of current rise, the pinching plasma acquires a large radial velocity and a dense plasma is created on the axis which may oscillate for several 'bounces' until it finally becomes unstable and breaks up. At the bounces, fusion reactions occur with the emission of neutrons.

In the early days, the production of neutrons was eagerly awaited as the signal that a thermonuclear reaction was taking place in the plasma. However, it soon became clear that the neutron yield was not altogether consistent with a thermonuclear process, and refined measurements with nuclear plates and cloud chambers on the directional distribution of the neutron energies showed that in fact the majority of the reactions were due to a small number of deuterons being accelerated in the direction of current flow to many times the mean thermal energy of the plasma. Deuteron energies corresponding to several times the potential difference across the tube were measured, and the origin of the acceleration process in still not fully understood.

The number of instability neutrons is in most cases large enough to make it impossible to determine whether or not a small fraction of the neutron yield is in fact thermonuclear. The neutrons, once so sought after, have now become almost an embarrassment. The whole question of 'thermonuclearity' has received more publicity than it has deserved; at the temperatures reached in these discharges (probably about 10^6 degrees) the thermonuclear yields would be marginal anyway, and it will not be until very much larger yields are obtained that the question will finally be settled.

The instability neutrons indicate that the processes occurring in the plasma are very much more complicated than were originally anticipated. Work directed towards understanding these processes, as much from the point of view of their importance in astrophysics as in the production of thermonuclear power, was reported from Sweden (147) and Germany (1056) where both experimental and theoretical work is in progress.

The fusion work at Harwell has been devoted to producing a quasi-static pinch of long duration in which inertial effects of plasma motion are not insignificant. This has lead to the construction of ZETA (1519) which is by far the largest of the operating pinch machines, although it was of great interest to learn that a close copy of ZETA, known as ALPHA, has just been completed in Russia. In the ZETA torus, 1m bore and 3m major diameter, currents of up to 200 kiloamps have been passed for several milliseconds, and considerable success in stabilizing the pinch has been achieved by applying a magnetic field along the axis of the current. This stabilization by external fields agrees quite well with theoretical predictions, and is also observed in straight pinches.

Future for ZETA

Measurements on the Doppler broadening of spectral lines suggest that the ion temperature in ZETA is of the order 10^6 °K. Neutrons are emitted for almost the entire duration of the current pulse. After the experiences of the straight pinches, extreme caution was necessary before attributing a thermonuclear origin to these neutrons. One of the first anomalies was that the yield was appreciably larger than would have been expected on the basis of the spectroscopic temperature measurements; later experiments confirmed that acceleration mechanisms were also at work in ZETA, and most of the neutrons were not thermonuclear. As in the fast pinch, their precise origin is still not clear. Very similar results have been obtained from a smaller apparatus, SCEPTRE III, at the AEI Research Laboratory, (3) Aldermaston, and from the American Perhapsatron S4 (2488).

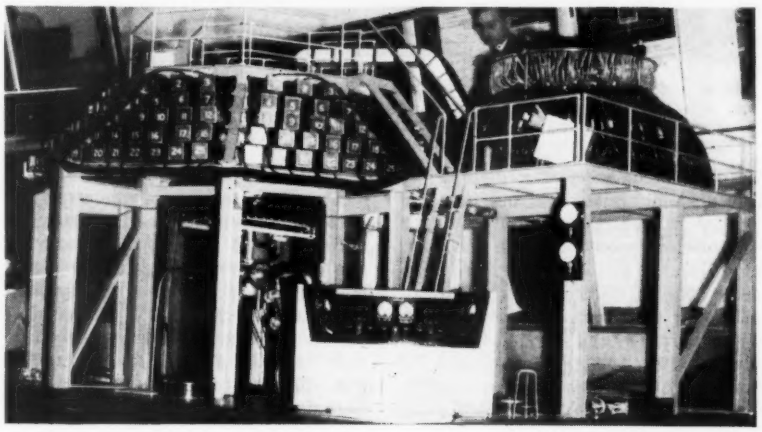
Of the various pinch experiments it seems that ZETA has a considerable advantage on account of its great size. This enables a time scale of milliseconds instead of microseconds to be used, which is a step in the right direction towards a reactor. At the same time it is clear that, in comparison with other pinch machines, ZETA is decidedly underpowered. Its condenser bank stores only 5.10^5 joules, whereas more than 10^6 joules are used in some of the smaller machines; it seems therefore that ZETA is capable of considerable development.

The simplest method of heating a plasma is the resistive dissipation of electrical energy. It is to be expected that as the temperature is increased and the plasma resistivity decreases, it will become increasingly difficult to continue heating in this way. A solution might be found by combining the rapid heating of the fast pinch with the long containment of the quasi-static pinch. It seems that to create a break-even reaction, currents of about ten million amps would be needed; such currents, although large by present standards, are well within the bounds of possibility, and the pinch approach, in spite of its difficulties, can still be regarded as promising.

The Stellarator

In pinch machines the current through the plasma serves both to heat and confine it. Other approaches aim at confining the plasma by externally produced magnetic fields and

The British cylindrical shock wave machine MAGGI was represented at Geneva by this one-third scale working replica—MINNI. It works by discharging 200 condensers simultaneously into a cylindrical tube. Results even on the small machine show that a good pinch is formed and that a burst of 10,000 to 100,000 neutrons per pulse are produced

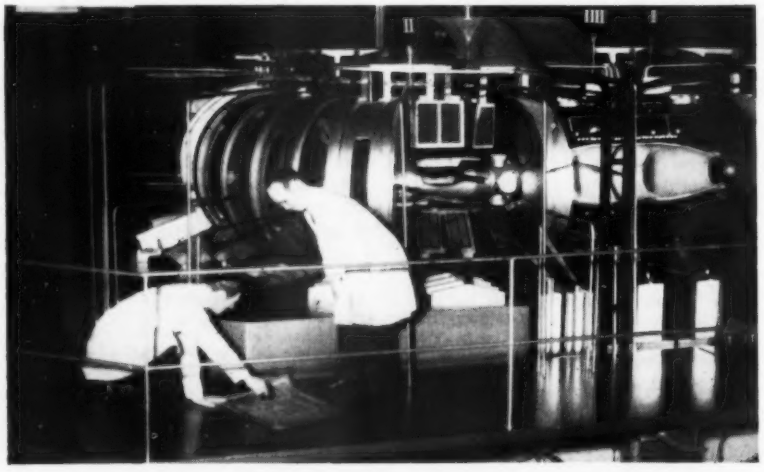


to heat it independently by other means. One such method is the STELLARATOR (2170), originally suggested by Professor Lyman Spitzer Jr, and being investigated by his group at Princeton University. This is essentially a completely closed magnetic bottle, produced by a series of coils wound on an endless tube. In its simplest form this would be a torus, but in this case a gradient of magnetic pressure arises out of the geometry and causes a drift of plasma to the outside wall. The first ingenious idea to counter this drift was to twist the torus into a figure of eight, so that each line of force, followed round the tube, traces out a path which brings it alternately on the inside and the outside of the tube. The plasma, moving freely along the lines of force, finds itself in an alternately reversed magnetic pressure gradient, and its tendency to drift in a preferred direction is thus cancelled. This twisting of the field lines is called 'rotational transformation,' and can also be achieved by a subsidiary spiral winding superimposed on the main field winding on a simple torus. This latter arrangement is theoretically more stable.

For the first stage of plasma heating, a current is induced by transformer action after the manner of toroidal pinch machines, but here the current is kept sufficiently low that instabilities do not occur. In this way, temperatures of about 10^6 °K have been obtained. Since resistive heating to higher temperatures would mean larger currents, and consequent instabilities, other means are needed to heat the plasma still further. Experiments have been carried out on heating by magnetic pumping, in which the magnetic field in one section of the STELLARATOR is rapidly varied. By arranging the frequency of this oscillation to be close to one of the fundamental frequencies of the plasma (either the collision frequency of the ions, or the cyclotron frequency of the ions in the confining field) it is theoretically possible to feed energy into the plasma, and it seems that this energy may be put preferentially into the ions rather than the electrons. Attempts to demonstrate this heating experimentally have only met with limited success, since radiofrequency power in considerable quantity is required and losses from the plasma at this stage are severe.

Aim is self-sustainment

The present STELLARATORS are fairly small machines, a few inches in diameter and with at total length of about twelve feet. A larger device, the C RESEARCH STELLARATOR, is at present under construction, and should be operational in 1960. This will employ a toroidal tube of 20 cm diameter in which a magnetic field of 50,000 gauss is produced. The heating of plasma to thermonuclear temperatures by magnetic pumping is anticipated, but it is emphasized that this is only an experimental machine.



Now under construction at Princeton the C RESEARCH STELLARATOR produces a rotation transformation of the plasma by spiral winding. In the model the magnetic pumping chamber can be seen to the right. The divertor for skimming contamination ions off the plasma is on the other side

The ultimate aim of the STELLARATOR is to produce a self-sustaining thermonuclear reaction. Once the plasma could be brought to 'ignition temperature,' it could in principle be made to keep itself hot if the reaction products were trapped by the magnetic field and gave up their energy to the plasma. The 'thermonuclear flame' could then be fed with cold deuterium, which it would burn as in a furnace.

Mirror machines

This is the generic name of a variety of devices which form a significant part of the American and Russian fusion projects. In Russia they are known as adiabatic traps. These employ a cylindrically symmetrical magnetic bottle in which the field is stronger at the ends than at the centre. The regions of higher field have the property of reflecting those plasma particles whose velocity vectors are inclined to the field lines at more than a certain angle; these particles will then remain trapped inside the bottle until a collision scatters them into an angle favourable for escape. At high temperatures collisions are infrequent and the escape angle can be made small if the ratio of the field at the ends to that at the centre is large. Thus although this bottle has a leak at each end, it can still be an effective container for plasma. It has the advantage of simple geometry and does not suffer from toroidal drifts.

Mirror machines may be divided into two groups according to the method used to heat the plasma. These are compression machines and injection machines. In the compression machines, reported from Livermore (377), plasma at low temperature is injected into the region between two magnetic mirrors. The field is then pulsed to a very high value (up to 2.10^5 gauss in some experiments) and the plasma, being tied to the field, is compressed and heated. This is the radial compression method; axial compression can be achieved by making the mirror fields move rapidly towards each other. The time for which the hot plasma remains in the machine after compression is an indication of the temperature reached. Plasma at several million degrees has been obtained and held in a small volume for the order of a millisecond.

A difficulty of this sort of machine is to reach really high temperatures in a single stage of compression. Machines with several stages have been built, in which after the first compression one of the magnetic mirrors is 'opened' by decreasing the field in it, and the plasma is transferred to another chamber where further compression takes place. The final stages, where large fields are required, can then take place in smaller chambers. Up to three stages of compression were reported. The initial filling of the machine with highly ionized plasma is one of the many technical problems involved, and this is at present injected from titanium hydride spark sources.

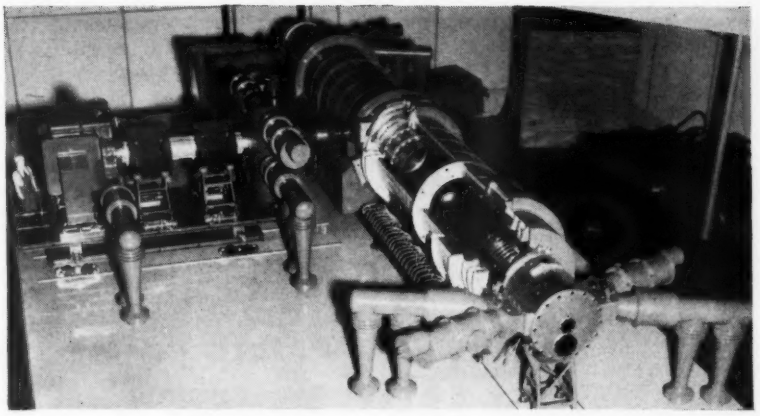
Experiments on very fast plasma compression were reported from ORNL (345) where a rapidly increasing mirror field is created by a heavy copper loop connected to a 'fast' condenser bank. Circular currents are induced in the plasma which interact with the field to produce the compression; this may be regarded as an inverse pinch effect, in which the currents and fields are interchanged. The resulting phenomena are similar to the fast pinch, and this machine, as well as a similar device called SCYLLA (356) at Los Alamos both produce neutrons on a microsecond time scale.

Perhaps the most interesting mirror machines are those which build up plasma inside their magnetic bottles by the injection of fast particles. The particles in a plasma at 10^9 °K would have a mean energy of about 100 keV. This energy is well within the range of very modest particle accelerators, which of course produce ordered beams, whereas in a plasma the particles have random velocities. It seems that many problems could be overcome if particles could be given their full energy outside the bottle, and could be randomized inside it to form a hot plasma. This would avoid going through stages at low temperature where the plasma losses are greatest.

A general feature of any static magnetic bottle is that a particle fired into it from the outside will perform an orbit which brings it out again. This can be avoided by injecting molecular ions, and breaking them up into atomic ions inside the bottle; the atomic ions have half the gyration radius of the molecular ions, and are therefore trapped.

Two bottles

This principle is used in the American DCX (344) and the Russian OGRA (2298). In the DCX a beam of about 1 mA at 600 kV is injected into a magnetic bottle of about a cubic metre volume, with 10 kilogauss central field and 20 kilogauss mirrors. In order to dissociate the molecular ions they are passed through a high current carbon arc inside the machine; this has been found to have a very high efficiency for dissociation, and circulating currents of about 15 A of deuterons have been set up inside the machine. It is intended that the deuterons should randomize their velocities by collisions with each other, but at present they are lost very rapidly by making charge-exchange collisions with neutral molecules of residual gas. If the injected current were increased by an order of magnitude, or the vacuum improved by a similar factor, the machine should act as its own pump and effectively remove the residual gas. This desirable condition, known as 'burnout,' has not yet been reached in the American machine.



The biggest thermonuclear machine yet, the Russian OGRA is a mirror device. It has only just been completed and no results were available. This is a model shown at Geneva

The Russian OGRA was of great interest as it is certainly the largest fusion research machine in existence. Its vacuum chamber is 1·4 m diameter and 12 m long, and its injector supplies about one ampere at 200 keV. The central field is 5000 gauss and the mirror fields are 8000 gauss. Unlike the DCX there is no internal arc for dissociation of the molecular beam; on account of the great size of the machine it is hoped that sufficient dissociation will occur first on the remaining neutral atoms in the vessel and, when these are 'burnt out,' on the trapped atomic ions. The OGRA has only just been completed, and no experimental results were available at the time of the Conference.

The ultimate goal of the steady-state injection mirror machines is to ignite a thermonuclear flame and then keep it confined in the mirror fields. As with the STELLARATOR, the scheme is very attractive on paper, but until plasmas have been produced in which substantial amounts of nuclear power are released it cannot be said whether this will be a practical possibility. In particular, instability problems may arise when appreciable densities of plasma are contained in this way.

Other machines

In addition to the three main streams of research, the pinch, the STELLARATOR and the mirror machines, a number of other devices were described and demonstrated. These included rotating plasma machines (the HOMOPOLAR (373) and IXION (2383)), radiofrequency machines (350), and an 'ion magnetron.' these are all contributing interesting information on the properties of plasma under different conditions.

One remarkable suggestion which must be included was the ASTRON (USA) (2446). Here it is planned to generate a magnetic bottle by a sheet current of relativistic electrons, the principle being that the electrons both provide a closed pattern of magnetic field lines and also heat the plasma. Experiments to test this principle have been started, but no indication of its feasibility has yet emerged.

The situation in the fusion field, as revealed by the papers at this Conference, seems to be that provided (a) instabilities can be controlled to such an extent that the drift of plasma across magnetic fields is given by 'classical' diffusion theory and (b) the radiation from a plasma is due only to *Bremmsstrahlung* and is not appreciably augmented by electron cyclotron radiation, a thermonuclear reactor is possible at least in principle. It may be a development of the pinch machines, mirror machines or the STELLARATOR, or more likely will combine features of them all. The possibility of some quite different approach proving more fruitful cannot of course be ruled out.

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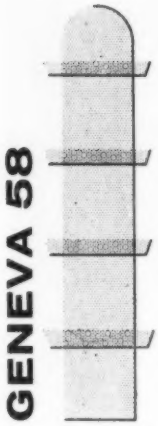
78 *UK* Controlled TN research *Thonemann*
2298 *USSR* Controlled TN research *Artsimovich*
2170 *USA* STELLARATOR programme *Spitzer et al.*
1064 *USA* Livermore programme *Cogate et al.*
1860 *USA* TN work at Los Alamos *Tuck et al.*
2301 *USSR* High current pulses *Andrianov et al.*
1460 *UK* High current discharges *Curran et al.*
147 *Sweden* Toroidal discharges *Siegbahn, Ohlin*
1056 *Germany* Recent CTN work *Biermann*
1519 *UK* ZETA *Thonemann et al.*
3 *UK* CTN work at AEI *Allibone*
2488 *USA* PERHAPSATRON S IV *Phillips et al*
377 *USA* PYROTRON programme *Post et al.*
345 *USA* High temperature plasma *Kolb*
356 *USA* SCYLLA *Boyer et al.*
344 *USA* Oak Ridge DCX *Bell et al.*
373 *USA* Rotating Plasma
2383 *USA* IXION, a T-N device
350 *USA* Radiofrequency thermonuclear machines
2446 *USA* ASTRON, Christofilos



by G. R. HALL, Ph.D.
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Chemical engineering developments

fuel reprocessing, heavy water, corrosion

EACH OF THE COUNTRIES with well developed nuclear power projects presented papers dealing with various aspects of the processing of irradiated fuels. This is illustrated by the fact that in the appropriate session, seventeen papers were chosen for verbal presentation, whilst a total of sixty-six papers were allocated to the session. The detailed discussions contained in some of the papers will undoubtedly provide much useful information to those countries who have still to plan their own chemical plants for fuel processing.

Criticality control

The development of the plutonium separation plant which has now been in continuous operation at Windscale for six years, is described in paper 307. A description of the complete process, from the fumeless dissolving of the uranium fuel elements, through the various solvent extraction stages (using solvent $\beta\ \beta'$ dibutoxy diethyl ether—*Butex*—for primary separation and uranium purification, and solvent tributyl phosphate—TBP—for plutonium purfication) to the final plutonium oxalate precipitation stage prior to metal production, is given and illustrated with detailed flow sheets. The importance of criticality control in the chemical plant is emphasized both in this paper and in others. This vital control together with the need to provide shielding protection from penetrating gamma radiation are two most important factors in which the nuclear chemical processing plant differs from the conventional chemical plant. Thus it is pointed out that in this plant criticality control is achieved by limiting the quantity of plutonium at any particular point in the plant. In the continuous processes safeguards are achieved by controlling the concentrations of plutonium in solution and arranging the geometry of the plant so that safe conditions are always achieved.

Paper 518, from the US Savannah River Laboratory, is devoted to a detailed description of some equipment which is designed to be critically safe. Mixer settlers, which are shaped in the form of slabs only three inches high, have been calculated to be critically safe for fissionable materials in concentrations up to 400 grams per litre of solution. A geometrically safe solvent washer in the form of a cylinder seven inches in diameter and twelve feet high has also been tested. Both these equipments have been tested and a layout in which a continuous washer is coupled directly to two mixer-settler units has been operated in a closed solvent circuit with 100 gallons of solvent. It is claimed that one ton of uranium, in nitric acid solution feed, could be processed per day in a similar layout. Although the equipment takes up a relatively small floor area, about six feet of space which is free of other equipment or neutron reflectors must be left above and below the slab settlers to maintain the slabs geometrically safe. The aim of this work is to design a small processing plant for the high concentrations of fissionable materials expected from fast reactors.

A new stainless steel

A number of papers describe special instrumentation which enable the plants to run almost entirely by remote control. In designing such devices it has always to be borne in mind that it may be impossible or certainly difficult to repair faulty equipment because of high levels of radioactive contamination. The French have described (1174) a special stainless steel which has particularly good stability in boiling nitric acid. It has the percentage composition Ni: 20, Cr: 25·7, Nb: 0·2, Si: 0·16, Mn: 0·39, C: 0·02, and has been used in the Marcoule extraction plant for the dissolving vessels and ancillary piping. The Marcoule plant has been designed to extract and purify the plutonium from the uranium fuel elements of the generating reactors G1, G2 and G3. The process and earlier pilot plant studies at Fontenay-aux-Roses are described in papers 1172 and 1174. The primary separation process i.e. removal of plutonium and uranium from fission products, is achieved in mixer settlers by solvent extraction using the solvent TBP with an organic diluent. The plutonium is subsequently separated from uranium by more solvent extraction stages and final concentration and purification is achieved by solvent extraction followed by an ion exchange stage.

An unusual variation of the solvent extraction process is suggested by AB Atomenergi of Sweden in paper 144. In place of the conventional countercurrent partition column, it is shown that an adequate separation of plutonium from uranium may be achieved by partition between the organic solvent and a stationary water phase absorbed on silica gel. Tracer scale experiments have been carried out, using TBP as solvent, but with conditions as in the American Purex process. It is claimed that the method could be adapted for use in a TBP flow sheet and would achieve, in addition to the separation of plutonium from uranium, a decontamination from zirconium in the primary separation stage. It would appear that a considerable amount of work has still to be done before a 'chromatographic column' process is a suitable substitute for the counter current column.

Descriptions of other aqueous separation processes in the USA, are given in papers 536, 1830, and 2409,

in Russia in papers 2182 and 2216, and for the Norwegian-Dutch Joint Establishment at Kjeller in Norway in paper 585.

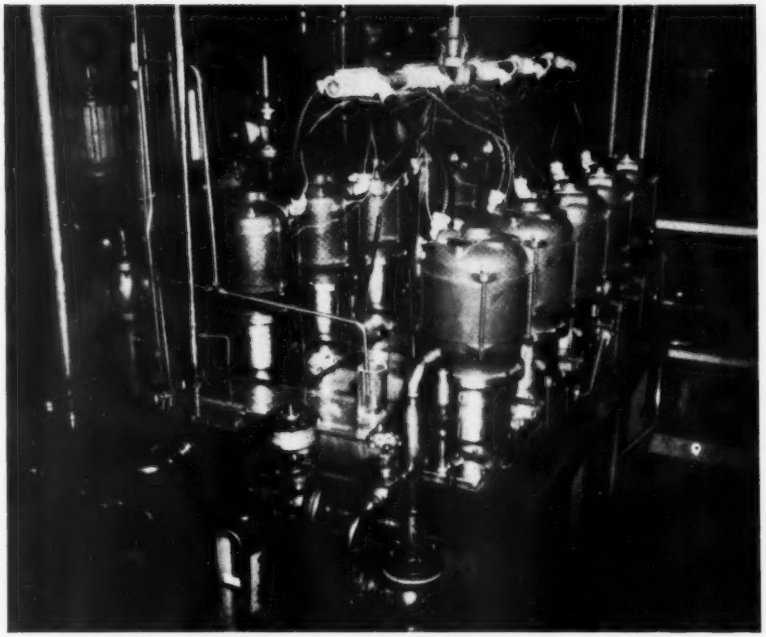
Dounreay processes

As new reactors come into operation and new fuels and canning materials are used, however, so modified processes become necessary for fuel processing. In a comprehensive paper (82) from the Industrial Group of the UKAEA, processes are described for the treatment of fuel from the DIDO-type reactors and the Dounreay Fast Reactor. The Dounreay Materials Testing Reactor chemical plant will process fuel elements in which enriched uranium is alloyed with a high proportion of a diluent, mainly aluminium. The DFR chemical plant will process fuel elements with only a small proportion of stabilizing elements added to the enriched uranium.

In the DMTR plant as much aluminium as possible is removed from the fuel element before transferring the fuel element to the dissolvers. Here great care has to be taken in criticality control and this is done by mass limitation. Subsequent purification of the uranium is by a TBP solvent extraction process using mixer settlers. In the fast reactor chemical plant particular care has to be taken during the cooling and subsequent dissolving of the fuel element.

The process is designed so that either uranium or plutonium fuels may be treated. The fuel element, on discharge from the reactor, is placed in a stainless steel tube containing lead which melts and immerses the element. The lead penetrates the can and displaces sodium, which is carried out from the reactor in the element, leaving a lead sodium alloy of varying composition. The stainless steel tube is then sealed and allowed to stand under water for the requisite cooling time i.e. to allow, in particular, I-131 and U-237 to decay. The plant is conceived as a horizontal arrangement based on mixer settlers and hence, as in the DMTR plant, the minimum of space and shielding concrete is used. In this case criticality control is based on plant geometry rather than operational control.

Flow sheets are given for both processes together with a description of important aspects of the plant. A centrifuge has been incorporated in the fast reactor plant to remove traces of solids from the active feed. This is an adaptation of the Sharples *Supercentrifuge* which is designed for continuous operation through heavy shielding and from which the filter bowl can be removed by remote control. The centrifuge requires no head of liquor to feed it, since the casing has been designed to pick up feed from the bottom of the casing and deliver it to the upper outlet after clarification. When the machine is not spinning, the feed builds up inside the casing and overflows from the lower outlet pipe to the next unit in the plant. In this way valves are not needed to by-pass the centrifuge.



For handling enriched solutions this slab mixer-settler was developed at the AEC Savannah River Laboratories. It is a ten-stage unit with a hold-up of 2 gallons per stage (paper 518)

It is interesting to note how the philosophy behind the design of radiochemical plants has changed as experience has been gained in the remote control operation of plant processes. Thus the Windscale plant uses gravity flow throughout the primary separation plant and, as a result, an enormous building some 200 ft high had to be built to contain the columns and provide shielding. Now, by use of mixer settlers a horizontal array of extraction units can be utilized and the cost of the building is greatly reduced. The use of the Sharples centrifuge illustrates another development in the growth of this new technology.

Thorium recovery

In the operation of the large radiochemical separation plants there is an accumulation of waste materials which consist of fissionable materials of considerable value. A description of the metal recovery plant at the US Oak Ridge National Laboratory for the treatment of such wastes forms an important part of paper 536. The plant has been designed to recover plutonium and uranium from irradiated uranium from a number of different reactors, for recovery of plutonium, americium, and neptunium from miscellaneous sources, to treat metallurgical wastes of all types, and also ash residues from the conversion of UO_2 to UF_6. The plant is designed to be remotely operated but directly maintained. The flowsheet is basically the Purex process and uses TBP as solvent. Plutonium is finally concentrated and purified by ion exchange. Highly active feed solutions are pumped by diaphragm sealed pumps and pulsed columns of 20-40 ft height are used for solvent extraction contactors. Paper 536 also described the Thorex pilot plant which is used for the recovery of U-233 from irradiated thorium. The maximum capacity of the plant is 150 kg of thorium per day with thorium metal slugs. As in the metal recovery plant the Thorex pilot plant is remotely operated and directly maintained. Major equipment is individually shielded by either cubicles or unit shielding, is easily accessible from a non-radioactive area, and is provided with built-in decontamination facilities. The basic process consists of extraction and co-stripping of the uranium and thorium in the first cycle followed by partitioning in the second cycle. The solvent is TBP and the uranium is finally purified by ion exchange.

The dissolution and feed preparation for aqueous radiochemical separation processes is discussed in considerable detail in paper 1930 which repre-

sents contributions from many firms under contract to the USAEC. It deals only with mechanical processes for clad fuel elements and fuel assemblies and new laboratory and pilot plant development data for the preparation of satisfactory aqueous feeds for solvent extraction processes. A distinction is drawn between 'disassembly' which refers to separation of structural components from active individual components of the complete fuel element, and 'dejacketing' which refers to the removal of cladding metal used to contain the fissionable or fertile material. The former is usually carried out by long-handled tong operation, milling or hacksawing under water. Dejacketing is a more difficult operation and can involve rolling, milling, extrusion, abrasive cutting, electrical discharge cutting and shearing. Each of these methods is discussed. Another method of dejacketing is, of course, dissolution and a considerable amount of experimental work is described for aluminium, zirconium, Zircaloy and stainless steel jackets. One particular aspect which has been extensively investigated is the dissolution of a stainless steel bearing fuel element; for instance the fuel plate for the Army Package Power Reactor is made up of enriched uranium dioxide sintered with 88 wtpc of stainless steel, and clad in stainless steel. A 'continuous Darex' process in which the fuel is dissolved in aqua regia of composition 5 N HNO_3—2N HCl, has been developed to deal with this problem. Up to now only small scale experiments have been attempted with irradiated fuels, but pilot plants are now under construction.

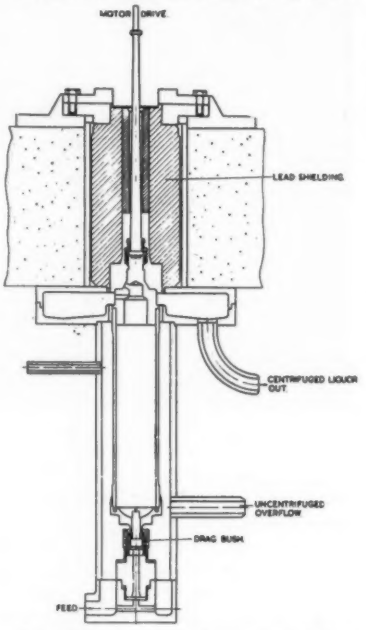
High temperature processing

In addition to the papers on aqueous processes there were several important contributions on solid or high temperature processes. Thus developments in pyrometallurgical processing and fluoride volatility processes in the USA are described in papers 1795, 1830 and 2388 and work in the UK on the possibility of processing reactor fuels with liquid metals in paper 32.

The feasibility of pyrometallurgical process is based on three main considerations:

1. The processes are often envisaged for fuels from fast reactors, where the impurity specifications are considerably relaxed by comparison with thermal reactors. This is because neutron capture cross sections in the higher energy region are generally low and there are no specific poisons with high resonance absorption in this region. Pyrometallurgical processing hence becomes a problem more of removing metallurgical poisons i.e. impurities which may be present in sufficient quantities to upset alloy systems or, in the case of liquid fuels, lead to dilution or segregation.

2. The limitations in aqueous methods, that are due to the effect of radiation in the processing of high burnup fuels are not experienced in pyrometallurgical processing.



A modified version of a commercially available centrifuge, this 'eversafe' model is used at Dounreay for separating the small amount of solids in enriched solutions (paper 82)

3. Pyrometallurgical plants are expected to be compact and hence their capital cost should be considerably less than for an aqueous processing plant.

These factors are discussed in papers 1830 and 1795. In the latter, the following operations are discussed: melt refining, solvent extraction using fused salts or liquid metals, fractional crystallization from low melting solvents, and electrorefining. Melt refining appears to have been most extensively investigated and it has been decided to incorporate this process into the fuel cycle of the US experimental breeder reactor, EBR-2. The method depends on the volatility of some fission products and the stability of the oxides of other fission products to separate these elements from the fuel alloys. Systems of enriched uranium, uranium-plutonium and fuel alloys which are basically plutonium (i.e. plutonium-cobalt and plutonium-iron alloys) have been investigated. Much of the work has involved synthetic alloys with added fission products (known as 'fissium') as starting material of high burnup was not available. A serious problem has been the choice of a suitable crucible for the refining process.

Another type of process which has been extensively investigated for several years is that of fluoride volatility. US papers 535, 539 and 2388 discuss recent developments in this field and the latter paper summarizes the work of a number of laboratories. In this process all the constituents of the spent fuel are converted to the fluorides and then advantage is taken of the difference in volatility of the fluorides, e.g. UF_6 may be recovered by distillation from the fission products and the diluting material fluorides. Attempts have been made to apply the process to plutonium-uranium alloy systems and to metallic alloys of enriched uranium-zirconium. In the latter, the alloy is dissolved in molten sodium fluoride - zirconium tetrafluoride at 600°C and hydrofluorinated to convert both uranium and zirconium to tetrafluorides and then the uranium is fluorinated to hexafluoride.

Reference has already been made to the use of solvent extraction using fused salts or liquid metal. This is discussed in paper 1795 with particularly reference to the processing of the uranium-bismuth fuel of the US liquid metal fuel reactor. Another application of this method is described in UK paper 32. Here it is shown that plutonium and a number of fission products may be removed from molten uranium by partition with calcium. Distribution coefficients for the fission products and several other likely impurities have been measured. It is suggested that a process may be envisaged in which the fuel is melted with calcium, the latter poured off, and the surface rewashed with clean calcium.

Heavy water production

From the papers submitted, three on heavy water production (1065, 1649 and 2323), dealing with work in the USA, India and the USSR respectively, were selected for verbal presentation. Paper 1065 describes the process for the concentration of heavy water at the US Savannah River Plant. The maximum production of 1,000,000 lb of heavy water per annum is extracted from natural water by a combination of three processes:

1. Dual temperature exchange between hydrogen sulphide and water.

The product from this stage yields about 15 pc D_2O. This part of the process is unfortunately not described, because of an injunction in the US courts.

2. Vacuum distillation, which increases the concentration to 90 pc D_2O.

3. Electrolysis, which takes the concentration up to 99·5 pc D_2O.

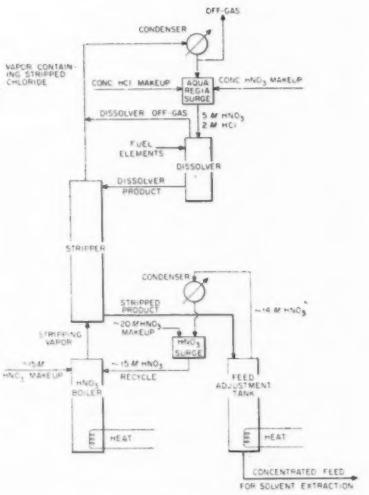
The vacuum distillation and electrolysis stages are discussed in some detail. The production cost when the plant works at full capacity and excluding capital charges is about $14 per lb (the selling price is $28 per lb). The authors also examine the possibility that a distillation process operating at one or two atmospheres absolute pressure, with vapour compression, might be worth reconsidering.

Paper 1649 describes Indian plans to provide 14 tons of heavy water per annum as a by-product at a fertilizer factory to be situated close to the Bhakra Nangal Dam scheme in the Punjab. After a consideration of various processes, it was decided to carry out the initial enrichment by electrolysis and final enrichment by low temperature hydrogen distillation. It is hoped to produce heavy water at a cost not exceeding the equivalent of $28 per lb.

It is very interesting to see that Constructors-John Brown have just issued a pamphlet in which they describe a plant that produces heavy water by a process based on a combination of ammonia exchange and ammonia distillation, as an ancillary to production of synthetic ammonia. It is economic to produce relatively small quantities of heavy water in this plant and it is claimed that the cost of producing 28 metric tonnes of heavy water annually in their plant is only £17 per kg (equivalent to $21·5 per lb).

Corrosion of reactor materials

As reactors are designed to operate at higher temperatures and neutron fluxes and as new types of fast reactors are developed, so does the problem of corrosion become more and more important. There were many papers describing different aspects of the problem distributed throughout several conference sessions. The more important work in this field was reported in sessions E14, E19 and E21. Here were found papers on the compatibility of fuel, coolant, moderator and canning material and, in particular, much discussion on fuel canning materials. Thus papers 194, 1993 and 2044 dealt with the corrosion of zirconium alloys. Zirconium is of particular interest for canning, because of its good thermal properties and low neutron absorption cross section. Paper 1944 described Chalk River experience on the stability of Zircaloy—2 (zirconium aluminium alloy) and aluminium-nickel-iron alloys in water at high temperatures. Although much work has already been published about Zircaloy—2, the purpose of the Canadian paper is to try and establish the mechanism of the infrequent failures of specimen Zircaloy-sheathed UO_2 fuel elements. It was suggested that failure occurs as a consequence of an interruption of heat flow through the sheath; this causes the temperature



A US Darex (Dilute Aqua Regia) flowsheet for reprocessing stainless steel/uranium fuel (paper 1930)

of the sheath to rise to a point where 'hydriding attack' can occur at the inner surface.

Another important aspect of the corrosion problem was discussed in paper 46 from Harwell. One of the important factors governing the design of a successful homogeneous aqueous power reactor is the choice of a suitable material for the reactor vessel. The two-zone 100 MW reactor, as envisaged at Harwell, might have an enriched uranyl salt solution in the core vessel and be surrounded by a thorium blanket. The core vessel is therefore subject to corrosion at temperatures of up to 300°C by aqueous fissionable material on the inside and an aqueous fertile material on the outside. From Oak Ridge results it can be shown that a Zircaloy—2 vessel will have far too great a corrosion rate under such conditions. There was a useful discussion of the various factors effecting such corrosion and a number of alternative materials for the core vessel were suggested. They include the possibility of lining the vessel with a material more resistant to corrosion than zirconium, and also the use of other alloys of zirconium. The problem is however still not solved and further experimental work is envisaged to attempt to reduce the corrosion rates. In this connexion paper 1993, from Oak Ridge, describes recent advances in the metallurgy of zirconium.

A comprehensive paper (2044) from the USSR gives the results of extensive experiments to investigate the corrosion of many zirconium alloys in water, steam and gases at elevated temperatures. Many of the samples used in these experiments weighed from 10-100 kg. The following criteria were used in judging the corrosion resistance of the alloys: change in weight of specimens with time, i.e. rate of film growth; continuity of the film and its adherence to the metal surface; ability to form a new film in those spots where it has become detached. A variety of alloys (with niobium, iron, tin and nickel) were recommended by the authors for their corrosion resistance in water and steam from 300-400°C. None of the experimental work has been repeated, however, in the presence of the radiation conditions to be expected if the alloys were used as reactor constructional materials.

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539 *USA* Recent developments in fluoride volatility processing of reactor fuels. *Steunenberg et al.*

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1065 *USA* Concentration of heavy water by distillation and electrolysis *Bebington*

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2182 *USSR* Some features of processing irradiated fuel elements at the first atomic power station in the USSR. *Shevchenko et al.*

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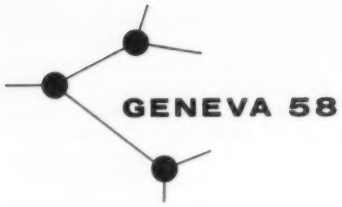

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Reactor physics and core calculations

new fundamental data and methods reported

Nuclear data and reactor theory

A variety of experimental measurements of neutron properties in reactors were dealt with in this session including measurements of reactor spectra by time of flight and integral measurements in many types of reactor cores, neutron temperature measurements, the slowing down of neutrons at low energies and the neutron spectrum emerging from a moderator. The problem of neutron thermalization at low energies was considered in both light and heavy media as well as the calculation of thermal neutron spectra and the calculation of transport cross-sections.

Paper 10 describes measurements of the neutron spectrum by integral methods (measurements of relative reaction rates of complete and cadmium shielded spectra) and by a pulsed source method. Measurements were made on a large number of critical or sub-critical assemblies including graphite-moderated lattices, light and heavy water moderated lattices as well as comparison between the spectra in pure moderators. Thermal and epithermal fission rates were also compared for U-233, U-235, Pu-239.

A survey of recent work in neutron thermalization (1839) covers the factors which affect the spectrum in a reactor, neutron moderation for various moderators in the region where the chemical binding effect is important, reactor experiments on spectra and new methods of calculation of spectra.

A method of calculating the neutron spectrum, illustrated by the case of an infinite homogeneous medium with graphite as moderator, is given in the British paper 18. This gives a method of calculating the neutron scattering law including the case for a crystalline moderator and discusses the solution of the Boltzmann equation for the neutron flux.

A paper from India (1638) gives a method for calculating the transport cross-section as a function of neutron energy in the thermal region for moderators using the general theory of the interaction of thermal neutrons with matter.

Reactor theory and computing methods

In this session the papers were concerned either with analytical methods of solution of the transport equation for different problems or with numerical methods of solution.

One of the main papers (2386) describes a particular method of solution of the transport equation which is a combination of analytical and numerical methods. It outlines the theory of the S_n method and then compares results obtained by this method with other methods and exact solutions of problems where they are known. The types of problem considered are homogeneous and inhomogeneous, the inhomogeneous problems dealing with different types of neutron source. Finally, there is a general discussion of the types of reactor problem for which this method has been satisfactorily used and a discussion on the computing time required for a typical reactor calculation using an electronic computer.

Two further papers (1691, 1692) consider a method of improving elementary diffusion theory by substituting a new formalism for solving constant velocity multiple scattering problems. This is opposed to the well-known method of using corrections derived from transport theory considerations. The method is used to illustrate the solution of a variety of problems. The albedo or half-space problem is completely evaluated and the result compared with four other methods of solution, including elementary diffusion theory. Other problems whose solutions are discussed are the reflexion and transmission of radiation by a plane slab, an isotropic source in the centre of a sphere and a sphere with a uniform isotropic source distribution.

The well known discrepancy between the measured and calculated values for the neutron age in hydrogenous media is reviewed in the American paper 2375. It points out that little has been done towards resolving this discrepancy since the first Geneva conference. Different methods of measuring the neutron age are discussed along with possible sources of error, but it is concluded that the measurements are accurate to a given quoted error. The exact methods of calculation are also reviewed and again they all give substantially the same result as each other, but a value different from that measured experimentally. It is concluded that the reason for the discrepancy remains unresolved.

Reactor physics

An extremely comprehensive and detailed paper (39) describes experiments and gives results of a large number of investigations with the zero energy fast reactors ZEPHYR and ZEUS. Many of the results reported for ZEPHYR are for the reactor when the original uranium envelope had been replaced by a graphite envelope. The types of measurement made are reactivity measurements, reaction rate distributions, reaction cross-sections at the core centre, integration of reaction rates, perturbation measurements, measurement of the delayed neutron fraction and the determination of the prompt neutron lifetime. For ZEUS, which was similar in dimensions to the Dounreay fast reactor, measurements

are reported of the critical mass for different core arrangements. In addition similar experiments are reported to those performed on ZEPHYR.

The state of methods of calculation for fast reactors with special reference to multigroup methods, is summarized in the American paper 637. The analysis of a number of different types of experiment is described including the critical mass, neutron spectra, prompt neutron lifetime, effective fraction of delayed neutrons, and exponential experiments. In addition, present day calculations on fast reactors are compared with those of three years ago and are found to be remarkably similar. Paper 592, also from the US, lists a large number of properties (kinetic, spectral, and perturbation) of a number of elementary fast reactors of different fissionable materials and composition.

Stability studies on a typical fast reactor, EBR-I, are discussed in 1845. Two particular dynamic characteristics are investigated: that due to the presence of a prompt positive power coefficient of reactivity which is outweighed by a slower negative coefficient, and an oscillatory instability which appears under abnormal operating conditions. Although the analysis given is not considered to be satisfactory, the positive coefficient of reactivity is thought to be caused by bowing of the fuel rods and so can be eliminated by proper design. In addition the instability is due to the presence of the negative coefficient of reactivity, occurring at some threshold power. A further analysis of the stability of fast reactors is contained in 1462, again with special reference to EBR-I.

The problem of a fast reactor accident is considered in 431. Two main types of case are considered of prompt neutron excursions. The first is where the core structure is intact at the inception of the burst and the second where the core structure has lost its rigidity and is collapsed due to high temperatures and/or external forces.

Heavy water lattices

The theory and measurement of lattices containing uranium and water were also described in this session, the main emphasis being on the use of heavy water as a moderator.

Two further papers, 212 and 590, deal specifically with natural uranium heavy water lattices. The first one, from Canada, describes and lists a large number of measurements of the buckling of natural uranium heavy water lattices and in addition gives results of five structure measurements on these lattices. These results are compared with diffusion theory calculations and a good correlation is obtained. The second paper is American and surveys the reactor physics of natural uranium heavy water lattices.

Paper 1841 summarizes methods of calculation and experimental results for light water moderated lattice with enriched uranium fuel. It is shown that the simple methods of calculation which are satisfactory for many other types of lattice are not accurate when light water is used as a moderator and so more refined methods have to be developed.

Beryllium moderators

The standard core of the MTR operates on 93 pc enriched U-235. Experiments have been performed to test the operation of the reactor using 20 pc enriched uranium and these are described in 1034. It is concluded firstly that the operating behaviour is essentially the same with the 20 pc as with the 93 pc enriched uranium; secondly, the higher ratio of fast to thermal compensates for the lower flux per MW; thirdly, that fuel element fabrication technology can produce elements capable of withstanding the full rigors of MTR core conditions; and fourthly, for research reactors, 20 pc enriched uranium can be considered equivalent to 93 pc enriched uranium if some care is experienced in locating beam holes to avoid the resonance structure in the spectrum caused by U-238.

Beryllium-moderated, enriched-uranium, zero energy reactors are discussed in the Russian paper 2146. The experiments were designed particularly to determine the critical mass of uranium, the lattice parameters and the effect of the Be-9 (n,2n) Be-8 reaction on the multiplication constant and the effect of the Be-9 (γ,n) Be-8 reaction on the kinetics of the reactors. The uranium contained 10 pc U-235 and experiments were performed in the range of beryllium/U-235 atoms of 1777 to 3112. Three types of system were studied: a critical system of core and reflector, a critical system with water in the fuel elements (76 hydrogen to 1 U-235 atoms), and a critical system containing additional water. All these systems were studied with and without a reflector of beryllium and a reflector of beryllium and water.

The reaction Be-9 (n,2n) Be-8 is given special consideration in 2276. It gives a method for calculating the effect of this reaction on the multiplication constant in a reactor. The method is similar in principle to that used to calculate the fast fission factor in a reactor and for a typical case the authors find an increase in the multiplication constant of 6·8 pc. This compares with the value quoted in the previous paper of 12 pc.

Graphite and light-water-moderated uranium and near uranium lattice measurements are reported in the British paper 40. This analyses the results in a different way from that previously used for this type of experiment, a two group analysis being used. Particular attention is paid to the averaging of diffusion parameters over the neutron velocity distribution. For the epithermal neutron group a definite velocity distribution has been chosen. The variable in the diffusion equations is defined as the reaction rate of $1/V$ detector having unit cross-section at a neutron velocity of 2200 m/s. Also the slow neutron group includes only those neutrons which have a Maxwellian velocity distribution.

Up to date little consideration has been given to enriched uranium graphite moderated systems. Paper 2408 gives details of a series of measurements in America on such types of lattice. Highly enriched uranium was used in the form of foils and the critical masses found for a number of different arrangements. The range of graphite to uranium atoms varying from 300 to 2500. The results of the experiments were analysed by these different methods.

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2375 *USA* Slowing down of neutrons in hydrogenous media *Goldstein et al.*
39 *UK* Experimental work with zero energy fast reactors *Sanders*
637 *USA* Physics of fast power reactors *Lowenstein & Okrent*
592 *USA* Properties of elementary fast neutron critical assemblies *Hansen*
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2408 *USA* Critical measurements and calculations for enriched-uranium graphite-moderated systems *Reynolds*

GENEVA 58

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Applications of radioisotopes

—the changing focus of industrial interest

IN VIEW of the opportunity for the discussion of these topics presented by the UNESCO conference in Paris last year it is not surprising that the papers covering the field at the Geneva meeting include relatively little really novel material. Nevertheless, even if the very numerous medical and biological contributions are excluded, about 8 per cent of the papers accepted deal with the industrial uses of radioactive substances. The changing focus of industrial interest is reflected in the larger proportion of papers devoted to the study of the effects of ionizing radiation and the vigorous attempts that are being made to find economic applications of radiation in the chemical industry. Indeed, almost as many papers are devoted to this topic as to the other industrial uses of radioactive substances.

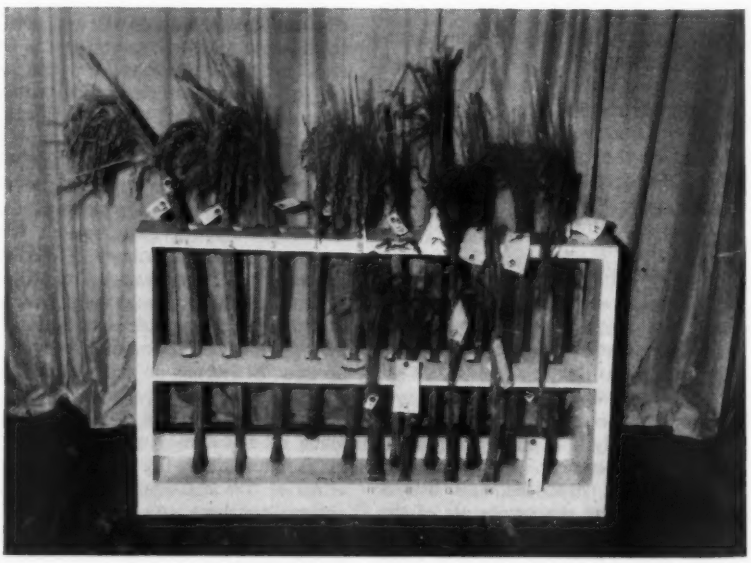
Induced mutations

Although this review deliberately excludes the bulk of the medical and biological studies, two aspects have been included because of their growing economic potential. Biological studies, especially those involving the larger organisms, necessarily proceed more slowly than the majority of physical investigations. The study of the mutations induced by irradiation began many years ago; the economic possibilities of plant breeding using the enhanced rate of mutation induced by irradiation were recognized as soon as radioactive materials became so cheaply available. Not unexpectedly such investigations have a particular appeal to the less developed countries where new strains of the principal food producing plants, if more suited to local conditions, might raise the standard of living more rapidly than any other development. Experiments on rice, wheat and other crops are lengthy investigations and as well as requiring numerous operators must be conducted in the appropriate environment. For these reasons the Brookhaven National Laboratory (USA) initiated a worldwide cooperative research project a few years ago and some of the results of these studies were presented at Geneva (2172). Already, for instance, a valuable new variety of wheat has been developed.

The other biological field still commanding considerable industrial attention is sterilization and food preservation. Again such studies take a great deal of time especially since the product must ultimately be proven on human subjects. Systematic studies of the effects of radiation on a variety of foodstuffs are proceeding steadily and various summaries of results were presented. Unfortunately a few of the most attractive possibilities seem unlikely to mature, either for economic reasons or because of undesirable side reactions spoiling the palatability of the product. These difficulties are especially relevant to all fatty materials.

Sterilization projects

The scope of the radiation sterilization in the pharmaceutical industry has been explored at Wantage in a project sponsored by the Association of the British Pharmaceutical Industry in conjunction with the Department of Pharmacy, University of London. For the sterilization of pharmaceutical products relatively large doses are necessary. At $2{\cdot}5 \times 10^6$r a variety of antibiotics could be sterilized without appreciable loss of potency. On the other hand organometallic pharmaceuticals such as the mercurials generally suffered extensive radiolysis. Many other products became discoloured with more or less



Shown at the scientific exhibition by Japan, these rice mutants show considerable morphological changes induced by irradiation of the seeds using P-32

modification of efficacy. Clearly further studies will be necessary to delineate the applicability of radiation sterilization (276, 807, 2071).

Roughly 50 papers deal with radiation effects and attempts to utilize radiation in industrial chemical synthesis, so that only a few noteworthy features in this group can be described. In dosimetry attention is directed to simple methods of measurement of large doses, accumulated at a high dose rate. The advantages of calorimetric methods of precision measurements have been emphasized and a particularly valuable review was presented by Koch *et al* (1927).

Work with plastics

The effects of radiation on polymers and plastics and, in particular, the use of radiation to effect copolymerization and graft polymerization continues to receive the greatest attention. Indeed the industrial possibilities of radiation-induced graft polymerization seem likely to provide one of the first economic applications of ionizing radiation—methyl methacrylate—polystyrene emulsions is but one promising example. An interesting example, teflon-polystyrene, studied by the discoverer, Magat, and a colleague, Chapiro, is shown in Fig 2. It is no exaggeration to observe that this is the only application of radiation with immediate industrial promise (65, 821, 826, 948, 963, 972, 962 802, 804, 2085, 1346, 1350, 2294).

The synthetic possibilities of ionizing radiation have not been neglected although it is observed that a radiation initiated synthesis will only be economically possible either in the few cases with abnormally high G values —that is to say radiation initiated chain reactions—or if the product cannot be produced economically in any other way (76). Reactions with high G values include, besides polymerizations, halogenations and oxidations. Generally the products have proved to be the same as those obtained by thermal reaction although the radiooxidation of benzene is reported to give a different distribution of products (65, 795, 797, 824, 962, 1287).

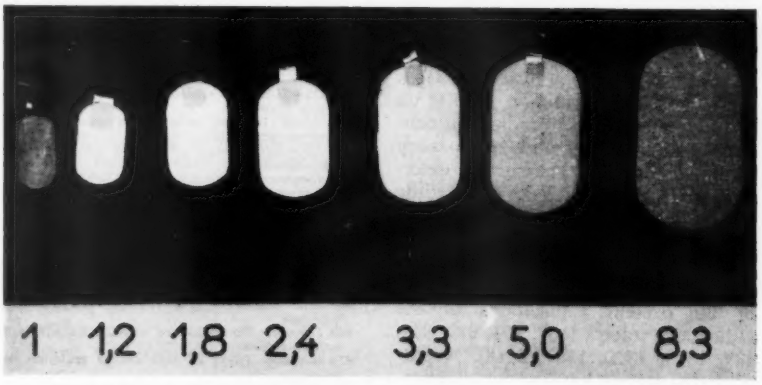
A number of new fundamental studies in radiation chemistry are reported, attention generally being focused on the radiolysis of organic molecules (51, 1122, 1516, 2384, 2293). One result of particular interest is the high radiation stability of the fluorocarbons compared with the chlorine, bromine and iodine compounds (922). The techniques of investigation of radiolysis have also received attention. The value of tracer methods is emphasized (928) and the application of electronparamagnetic resonance methods to the radiolysis of organic solids is described (113, 2079). This latter technique seems likely to prove of great value.

At best perhaps 2 pc of the energy released in a reactor might be stored as chemical energy so that radiation chemistry does not provide us with a means of tapping nuclear power more efficiently (76, 1125). However, certain branches of the chemical industry, for example, the pulp and paper industries, are large consumers of low grade heat which can be provided very easily even by primitive reactors. The economic aspects of combining reactor operation for isotope production with the sale of low grade heat for chemical processing is now receiving serious attention (76, 495).

The few papers on activation analysis (796, 841, 858, 936, 953, 984, 2023), contain little that is new but a method for the estimation of small amounts of oxygen in metals, proposed by Smales a few years ago, has been utilized at Oak Ridge (927). The method is unusual in that the activation takes place through an intermediary. The metal is mixed with lithium fluoride and then irradiated with neutrons. Tritons released by the (n,t) reaction in the lithium produced F-18 by the (t,n) reaction in 0-16; the activity of the F-18 is then measured, if necessary after a chemical separation. 1 ppm of oxygen can be determined in the surface of the metal.

A novel and potentially most valuable non-destructive method of analysis was described in a paper by Cook *et al* (285). It consists in fluorescent excitation of the characteristic X-radiation of the sample by irradiation using an orbital electron capturing isotope. The fluorescent radiation is then examined with a proportional counter and pulse analyser. Each element present in the sample then produces a peak whose height is proportional to its concentration. As yet elements of adjacent atomic number cannot be resolved.

As far as the production of radioactive materials is concerned, beyond a few reviews of conventional processes attention is divided between large-scale separation plants for specific fission products such as Cs-137 (831, 1768, 1235) and new methods of producing complex molecules tagged with C-14 or T. Wolfgang's self-labelling technique for tritiated compounds has now been extended to C-14 compounds: indeed, the radiation can be provided by another species, conveniently Kr-85. Thus if an organic compound is mixed with Kr-85 and $^{14}CO_2$ or $^{14}C_2H_2$, radiocarbon derivations of the organic compounds are produced. The nature of the products and their relation to the initial material have been investigated in order to exploit the process for the production of known labelled compounds. In most cases several radioactive products are produced and the proportion of radiocarbon in any one is small. However specific activities are high and very complex labelled molecules may be obtained in this way (284, 724, 798, 848, 1426 and 935). Labelling by recoiling T and C-14 atoms also received close attention and a better understanding of their complex reactions has been obtained.



These teflon-polystyrene graft polymers were produced by French workers using gamma irradiation. Initial teflon specimen is on the left and those to the right contained increasing amounts of polystyrene, as shown by the figures

Thickness and level gauges

A number of countries presented reviews of their application of radioactive substances (166 Sweden, 216 Canada, 985 Germany, 1101 Finland, 1231 France, 1321 Japan, 2308 USSR, 1431 US Petroleum Industry). For the most part they describe elaborations of existing procedures.

Radioactive thickness gauges, levels and similar devices are reported in a

number of papers (125, 827, 981, 982, 983, 1794, 2235, 1349, 1347, 1435, 2120). A new departure is the use of soft X-ray scattering gauges to measure the weight per unit length of wires and the thickness of coatings on curved surfaces. Such a device requires a soft X-ray source for which a pure K-capturing isotope such as Fe-55 is suitable (285). An essentially similar device using a Co-60 source fitted in a sonde behind a counter screened from direct radiation is described for the study of the density of earth strata in the coal industry (283). A neutron scattering gauge for moisture determinations as well as an alpha thickness gauge for paper is also described.

Widespread industrial use

The remainder of the industrial applications cover nearly 60 papers. The USSR and some Eastern European countries describe a number of studies in the heavy metallurgical industries. A Hungarian contribution reports on a study of the liquid profile in a continuous steel casting installation using saturated tungsten spheres to determine the depth and P-32 to give the complete profile (2240). Numerous flow, mixing and diffusion studies are included and their simple applications are indeed probably the most valuable of the present applications of the radioactive tracers (167, 803, 817, 834, 987, 1348, 1820, 1981, 2218). A particularly interesting special application of this concerns the flow of surface water in different parts of Israel and very valuable information has been obtained by tracer methods (1613, 1614). Another unusual, but methodologically related, study concerns the measurement of the multiplication of bacteria by tracers (820).

Another small group of papers report on information that is of such widespread importance that it is difficult to assess its value. Events of the last four years, in particular thermonuclear explosions, have provided the meteorologist and the oceanographer with a remarkable opportunity to learn more of the movement of air and water in these two regions. The equilibration of the newly released T and C-14 with the surface reservoirs of these elements is now being studied and a great deal of valuable information is being obtained (403, 176, 1536, 1626, 1982, 2128, 2370). Thus the previously supposed slow exchange of the atmospheres of the northern and southern hemispheres has been confirmed. A number of quite unexpected activities are appearing in minute amounts in rain water—for example Mn-54 and Co-57 (2285).

Measurement of thickness of pipe walls or sheet materials when there is access to one side only can be performed with a gamma backscatter gauge. The measuring head of this British model using cobalt-60 is fitted with a spring-loaded applicator jig to ensure accurately repeatable position of the head

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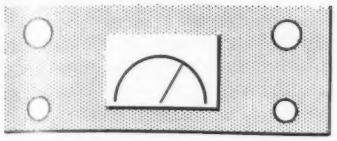

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Nucleonic and reactor instrumentation

— not a big section, but emphasis on health and safety

INSTRUMENTATION did not feature as an independent session at the conference, but papers were included in the various specialist sessions, e.g. those concerned with reactor kinetics and control, reactor safety, radiological protection, dosimetry, prospecting, etc, which discussed the instrumentation aspects of the problem. This report outlines some of these instrumentation developments, and comments as to how they fit into the general picture.

Health physics instrumentation

Whole-body monitors using either high-pressure ionization chambers or scintillation counters were the subject of a number of papers. This technique of measurement has developed into a very valuable health physics tool. It is also apparent that these monitors provide useful tools in connexion with problems of reactor safety and waste disposal, particularly in cases of litigation over alleged instances of contamination. In its simplest form the apparatus comprises one large crystal (say, of the order of 5 in. diameter) and a photomultiplier counting circuit. In this event pulse analysis will permit identification of the emitters and collimation will permit their location. The British paper 1476 and 762 from the US describe the apparatus actually employed and discuss the type of performance obtainable with this low-intensity spectrometry. Employing these techniques it has been possible to identify, locate and measure less than 10^{-9} curie of gamma-ray emitters in the body and follow the transport of these elements from one organ to another. As a result accurate data has been obtained on the elimination rates from the whole body, on clearance rates from particular organs such as the lungs, and on the fraction of the total inhaled quantity retained in the body.

It should be noted that normal unexposed humans contain at least two

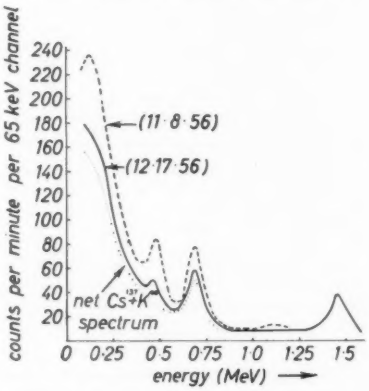


Fig 1 Gamma ray spectrum from human subject containing tellurium-129

radioactive elements and so a measurement which gives only the total number of gamma rays leaving the body per minute without information as to their energies is useless. It is for this reason that the sodium iodide scintillators tend to be used in most modern whole-body monitors because of the very good energy resolution which this scintillator provides. The two radioactive elements normally present even with the unexposed persons are K-40 and Cs-137, and hence the analysis of *in vivo* spectra to determine the contamination present in the case of exposed persons involves subtracting the subjects' Cs and K spectra from the subjects' gross spectrum. Figure 1 shows the analysis (taken from 762) of the gamma-ray spectra of a subject containing Te-129.

The whole-body monitor can also be used for measurements of beta as well as gamma-emitters by taking advantage of the *Bremsstrahlung* emitted. In recent times whole-body monitors have also been found useful for investigating articles contaminated by the escape of radioactivity as a result of a reactor accident — this was referred to at the conference by more than one speaker.

Control of health hazards in handling plutonium is obviously a matter which will become more important as the use of plutonium for peaceful purposes increases. An informative paper on the subject was the American 760 but there was special interest in the problem of detecting plutonium in wounds. This latter was the subject of three papers: 60 from the UK and 756 and 759 from the US. The first two considered the same technique, namely detecting and locating the plutonium by monitoring the 17KeV X-ray emissions, using a thin crystal counter. The alpha rays have insufficient penetrating power to be detected in the case of absorbed plutonium, but the 17KeV X-rays have. A crystal of NaI, 0·25 mm thick, gives about 95 pc detection efficiency with these 17KeV X-rays and a sensitivity down to about 0·002 microcurie is thus possible. The apparatus comprises a small scintillator at the top of a cone-shaped light-guide feeding the pulses to the photocathode of a photomultiplier tube. The voltage pulses are fed to a single-channel pulse analyser with the channel centred on the 17KeV emissions. Backgrounds of the order of 1 count per

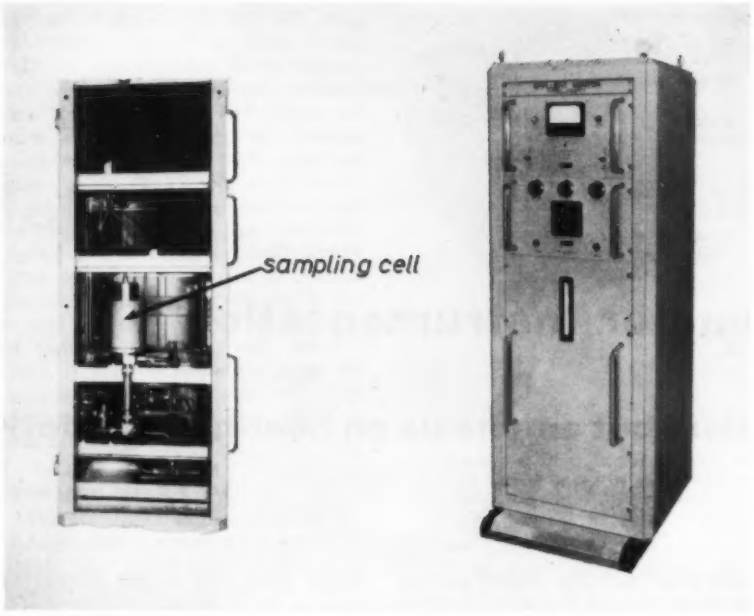


Fig 2 A British effluent monitor. The cell is provided with a plastic lining which is replaced when surface contamination builds up to a predetermined percentage of the actual sample activity. By washing the cell daily as part of the sampling cycle, build-up of activity is slow

minute are possible with this form of apparatus allowing the detection of small fractions of a mpbb.

Paper 756 records three cases of the actual detection of plutonium in wounds to illustrate the technique. In all these cases the wounds were in the hands and so it was possible to place the counter in a small cave made of two-inch lead bricks and the person's hand was inserted through a small hole in the cave. With this form of apparatus it was possible to locate a minimum detectable amount of 0·0004 microcurie, i.e. 0·1 pc of a mpbb. They found it convenient to determine the actual location of the plutonium contamination by the use of a slit cut in a thin piece of lead interposed between the counter and the hand.

Designers of health physics instruments were interested in a paper by EMI Ltd. (294) describing their instrument for the simultaneous hand and clothing checking for alpha and beta contamination. This represents a real advance over existing techniques of measurement.

A great deal of interest was centred on the treatment of radioactive wastes. The instrumentation aspects were not given any real prominence, but there is an obvious trend to provide equipment for the continuous monitoring of liquid effluents and for the automatic control of the discharge of effluents from chemical plants, reactor plants, etc. One form of apparatus which was described is shown in fig. 2. A sample of the effluent liquor is drawn off from the effluent line continuously and passes into a sampling cell. This allows the activity measurement to be made under conditions of good geometry and low background counting rate, i.e. high sensitivity. The cell is being filled continuously and overflows back into the exit pipe.

The apparatus shown in the figure also includes facilities for measuring the flow rate as well as the activity per unit volume. Both these quantities and their variation with time during the effluent discharge cycle are recorded, and it is usual in some installations to feed these two quantities into an electronic multiplying circuit feeding into a drum register which clocks up the total activity discharged since the beginning of the discharge cycle. Paper 394 describes an automatic waste stream analyser which carries this principle further by introducing an activity measurement with suitable energy discrimination to separate the activity into three channels corresponding to the Rh-106, Ru-103 and I-131 activities.

A paper which created special interest was 235 from Switzerland which described a novel technique—the use of thermoluminescence for dosimetry. The method consists in exposing a suitable material (natural and artificially made fluorites are suitable) to the radiation and then measuring the thermoluminescence glow curve. The heights of the first three maxima are strictly proportional to the dosage of irradiation up to a dosage of 2000 or 3000r. The measurement therefore involves flash heating the sample (at a velocity of about 100°C/sec) and measuring the light intensity with a photomultiplier. There are some practical difficulties because of fading effects, but as the measuring apparatus involved is much the same as with the metaphosphate glass type of dosimeter,* it would not appear to offer real advantages over existing methods.

Measurement systems for high level dosimetry is a subject of considerable importance at the present time with the widening application of high level irradiation, particularly in connexion with food preservation problems. The paper outlines a consistent and practical system for gamma-ray and X-ray dosimetry in the absorbed dose range from 10^4 to 10^7 rads (1909).

Prospecting and mining instruments

The design and performance of geological instruments was dealt with in several papers. One, by members of the US Geological Survey (1909), describes a number of novel instruments. These include a solid phosphor core scanner for measuring the activities of drill core samples, a time interval differentiator — an apparatus to aid the analysis of natural radioactive gases which depends on the fact that the naturally occurring isotopes of radon decay into isotopes of polonium having widely different half lives—and an alpha/gamma logging equipment for the search and evaluation of uranium-bearing ores. The corresponding British contribution (299) gives special emphasis to the use of scintillating counter techniques both for ground prospecting instruments as well as aerial survey purposes. A parallel paper was presented by A. S. Bhatnagar of India (1667).

The precise radiometric determination of the uranium and thorium contents in ores was the subject of a paper by the Italian delegation (1398). This gives a survey of the various integral and differential methods as well as the method of counting the U-235 fission products after neutron irradiation of the sample.

Control instruments

One of the most interesting papers dealing with measurement and control was 827, US. One of the techniques described was the determination of beryllium in the microgram range using the (α, η, γ) reaction. The beryllium is collected on a millipore filter and then the filter is examined

* See for example, Taylor, D., 'Radiac Instrumentation' *Journal of Scientific Instruments*, 1952, 29 (Oct) pp 315-322

in the laboratory using an alpha-source of polonium (Po-210) and a NaI scintillator. Beryllium can be determined in the one microgram range with a 6 minute counting time and by using a longer counting time it should be possible to extend the measurement range down to at least 0·2 microgram. It is understood that this same method is being developed for the continuous monitoring of beryllium in the UKAEA factories.

Another method which is described in Reiffel's paper is that using a promethium-147 beta source to excite K-band X-rays in contaminants collected with a high volume air sampler on a filter paper. A specific element of interest is lead and a method has been developed which permits lead concentration determinations in industrial environments in a total air sampling and counting time of the order of 15 minutes. At present a thin NaI scintillator has been used and allows lead determinations in the milligram range, but the use of a pressurized gas-filled proportional counter is being developed which should reduce the background problem and also increase the discrimination against other elements.

Reactor instrumentation

There were several papers on detector systems including 2084 from USSR, 493 from Yugoslavia, the French 1207 and Britain's 56. The Russian paper indicated that the workers in the USSR and in the West are following much the same lines in these developments. It is perhaps of interest to note that the Russians have found it convenient to use an electrode system comprising a multiplicity of disks, a construction which was used some years ago* by British workers, but chambers with cylindrical geometry seem to be standard over here and in the US at the present time.

The British paper described the development of British neutron detectors (ionization chambers, fission counters and gas proportional counters) and in particular describes the improvements which have taken place for high temperature operation. For operation at temperatures in the range 250° to 450°C a stainless steel construction is used. The paper also discusses the type of apparatus which can be used for the measurement of the direct current which is obtained from these neutron-sensitive ionization chambers when used for the measurement of neutron flux. In all cases the detectors considered have been designed for use in a thermal column, so that it must be assumed that the proportion of neutrons escaping into the thermal column is constant and independent of the actual power level for this method of measurement to give a proper index of the total neutron population in the reactor core. None of the papers discuss the important matter of in-pile detectors for which there is now a real need.

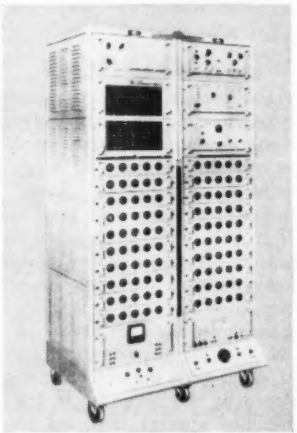
Paper 1207 from France discusses an alternative approach to the problem of neutron flux measurement, namely the method of using a uranium source which on bombardment with neutrons emits fission products which can be detected by the ionization produced.

Some of the later papers describe the control system to be adopted in future stations. These included paper 85 describing the overall control of the SSEB station to be built at Hunterston. Paper 213 on the control of Canadian reactors created a large amount of interest. It describes the important features of Canadian practice as:

1. triplication of all important control and safety instrumentation and circuits, and the use of the coincidence or two-out-of-three principle
2. continuous intercomparison of control and safety information from identical channels
3. the use of routine testing procedures without interference with reactor operation
4. relatively fast automatic-start-up methods
5. reactivity control by moderator-level variation
6. the 'safeguard-bank' principle.

There were also some papers presented relating to the development of special instrumentation systems for reactor plants. These included one from Britain on the detection of burst fuel elements in nuclear reactors (57) and a parallel French paper (334). The British paper outlines the techniques used in the case of water-moderated and cooled reactors as well as the gas-cooled types. It also outlines an improvement in the wire machine which replaces the wire with a reciprocating rod. This gives a real improvement in the reliability of the device, is very much simpler, but suffers from the disadvantage that the build-up of activity of the rod in certain circumstances (when starting up the reactor from 'cold') is reduced compared with the wire machine. Fortunately there is sensitivity in hand and so this 'rod' type precipitator finds many applications—it is used, for example on DIDO type reactors. The French have carried this idea a little further by using a fixed electrode in the detector system (i.e. the scintillator) itself. Again the same disadvantages are encountered, plus another one due to increased sensitivity of the system to gas activity, further reducing the sensitivity, but this compromise solution can be adopted in quite a number of cases.

Papers on general instrument design were not encouraged, but one on this topic was 1210 (France) in which a system is described of using standard chassis and racks to permit the rapid design and assembly of nuclear instruments. Figure 3 shows one of their completed instruments.



A French kicksorter for neutron time-of-flight spectrometry built up largely from standard chassis and racks. At the scientific exhibition an improved transistorized version of this 100-channel instrument was shown

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759 *US* Sensitive analytical method for determining very low-level plutonium in humans
294 *UK* Simultaneous hand and clothing checking for alpha and beta contamination *Brown*
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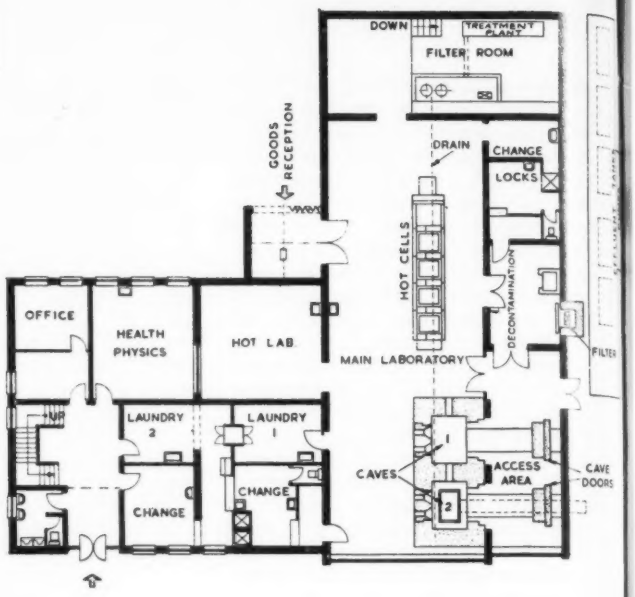
1927 *US* Measurement systems for high-level dosimetry *Hart et al.*
1909 *US* Developments in radiation detecting equipment
299 *UK* Recent developments in instrumentation for survey, assay and mining of radioactive raw materials *Bisby et al.*
1667 *India* Development of devices for radioassay *Bhatnagar*
827 *US* Measurement and control methods using radiation
1398 *Italy* Precise radiometric determination of U and Th in ores
2084 *USSR* Boron ion chambers for reactors
493 *Yugoslavia* Role of impurities and radius effect in BF_3 proportional counters *Milogeric*
1207 *France* A new detector for the measurement of neutron flux in nuclear reactors
56 *UK* Overall control of GC reactors *Smith*
213 *Canada* The control of Canadian nuclear reactors *Pearson et al.*
57 *UK* Detection of burst fuel elements *Hough et al.*
334 *France* Detection of bursts in French reactors
1210 *France* Advances in nucleonics *Doireau et al.*

* Jaques, T. A. J., Ballenger, H. A., and Wade, F. 'Neutron Detectors for Reactor Instrumentation' *Proc IEE*, 1952, *100* (Dec) p 110

Radioactive metals laboratory

Metrovick builds first privately-owned hot facility in the UK

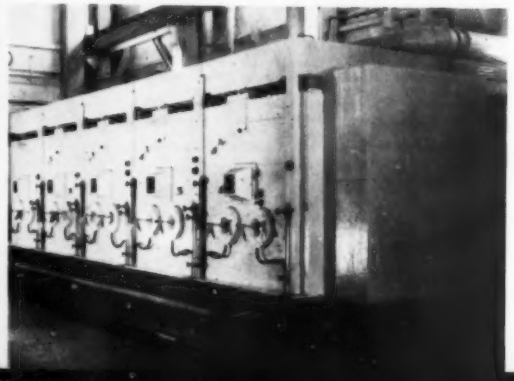


THE SUCCESS of Britain's next step forward in nuclear power station development—from the first round stations to the advanced gas-cooled reactor and then to the high temperature version—will hinge very largely on the solution of metallurgical problems centering round the fuel elements. Up to now facilities for studying irradiated metals have been built only by the Atomic Energy Authority, but in the end the industrial groups will want to be able to stand on their own feet, and a move in this direction has been made by the Metropolitan-Vickers Electrical Co Ltd. Almost ready to go into action at Wythenshawe is a laboratory built and equipped for investigating the effects of radiation on reactor materials and NUCLEAR POWER was recently invited to pay it a visit.

The culmination of two year's planning and building, this Radioactive Metals Laboratory contains two barytes concrete caves, a train of five interconnected lead-walled cells, a hot laboratory, health laboratory and changing and laundry facilities. The 8 × 6 ft, 11 ft high caves are built from 3·4 g/cc concrete blocks joined by lead sheet and lined with tinned sheet steel painted with epoxy resin. They can accommodate complete fuel elements or even test rigs, and access is by means of 25 ton doors extending to the full height and mounted on roller bearing 'skates.'

Work will be controlled from outside the 3 ft thick walls by standard Savage & Parsons manipulators and viewed by Pye closed-circuit television equipment, supplemented by two 2 ft thick lead glass peepholes for each cave. One cave will be used for dissecting fuel elements under water with the aid of a machine developed by the company: it will strip off the fuel element cans and cut out sections of the can or the element itself. The use for the second cave has not been settled yet—though mechanical testing is a possibility.

Manipulated from outside this line of lead walled cells a radioactive specimen can be passed from one to the other for treatment. In the last cell it is photographed through a microscope and its hardness determined



Remotely cut, weighed, tested

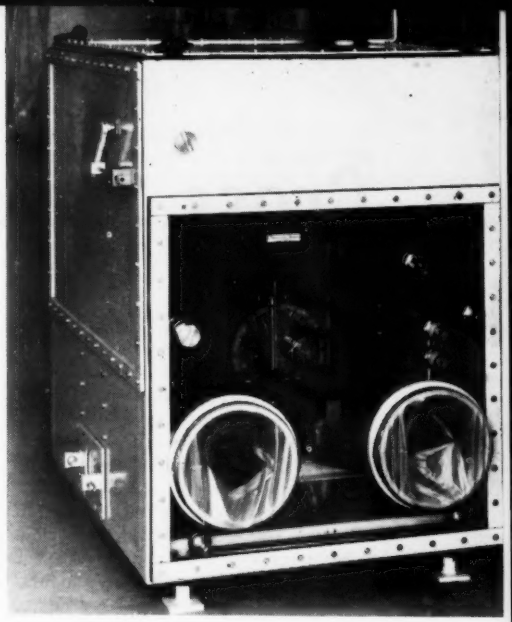
After cutting, a typical specimen measuring say ¼ in. thick by 1 in. dia, will be moved from the caves to the first cell a few feet away in a small lead coffin, which is run up on a stand; it will be pushed through the ports of the coffin and cell into an inner container of steel and Perspex by a transfer mechanism which deposits it on a tray at the end of a movable arm. When the ports have been closed and the coffin taken away the arm moves down so that the sample can be lifted out of the tray by one of two spherically mounted handling tongs. It is then weighed and its density determined by an *Oertling* balance on which all weighing can be carried out by the addition and removal of riders which are remotely operated from outside the cell. Next the specimen is mounted in cold setting resin by an automatic device in the cell and put in the transfer tray for sending through the port into No 2 cell, which is equipped with three standard automatic polishing machines. Here it is rough-ground, polished, and lapped to a suitable finish, the polythene and carborundum laps being changed by the handling tongs. After attack-polishing, electro-polishing and anodizing in the third and fourth cells, it is moved into No 5 for the final examination. This cell, which dispenses with the inner container, is fitted with a Brown-Firth variable load hardness testing machine and a Reichert microscope modified for the company so that the viewing system incorporates two right angle bends to cut out any direct paths for radiation. It will be illuminated and operated from outside the cell and the optical system brings the image out to a camera so that a photographic record of the specimen can be obtained. Controls on all five cells are brought through the 6 in. lead walls where necessary, but they can be disconnected and the concrete roof on any cell removed to lift out the inner container as a whole for cleaning and decontamination.

The designers have put considerable thought into the safety aspects of the plant, and in addition to personnel monitors between the changing rooms, and portable instruments, two Rotheroe and Mitchell recording alpha dust monitors (see August, p 370) are used, one in the main laboratory and the other in the main air extraction duct. These sound a klaxon alarm if the level of radioactivity rises unduly. The second also automatically switches in a bank of *Poelman* filters in the ventilation chamber by means of an electromagnetic valve to stop any contamination escaping from the building. These filter units can be removed and replaced remotely but since all air from contaminated chambers is filtered locally they are purely a second line of defence. In the main laboratory

air is extracted from the interior of the concrete caves via local filters and from the spaces between the sealed containers and lead walls of the small cells so that all these units are at reduced pressure and the air flow is directed away from the operators.

Contaminated water from the cells, caves and decontamination room is conveyed by copper drain pipes to the filter room where it is passed through batteries of ceramic candle filters in a screened cell and then sent through an expendable cartridge type ion exchange unit before pumping into a holding tank. The water filters, and an air filter in the cell, can be changed remotely.

Besides examining materials irradiated in research reactors the laboratory will be able to help in dealing with any problems which might arise when the 250 MW Berkeley power station gets under way. It has been designed to allow as much flexibility as possible, and one end of the main laboratory consists of a large glass window. The idea is that an extension could easily be built on without interrupting the work. Though the whole idea behind the project is to make the company self sufficient the engineer in charge, T. Starling, told NUCLEAR POWER that they were grateful to the Atomic Energy Authority, who have cooperated throughout and are providing some work to help the company gain experience.



Each of the cells in the background contains an inner steel and Perspex container which can be lifted out for decontamination. This one is used for weighing a specimen by means of the remotely controlled Oertling balance inside

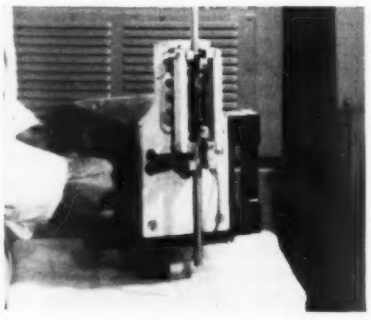
Brazing by remote control

Induction heating finds applications in atomic energy

THE EASE with which brazing can be carried out by remote control using induction heating has led to several applications of the technique in the atomic energy industry. Basically the heat is generated in the work by circulating eddy currents induced by some form of work coil or inductor which is energized by a high frequency generator. Chief advantages are that the heat is produced in the work extremely rapidly —keeping distortion and oxidization to a minimum—and it can be localized in any desired part of the workpiece. A firm which has taken a prominent part in developing the technique is Delapena & Son and NUCLEAR POWER went to see their Cheltenham factory recently. Though this is only one side of the company's activities, it is called on to carry out a wide variety of jobs, and work in progress ranges from items for the AEA to precision profile hardening of gears under water.

One of the first applications of Delapena equipment in atomic energy was the brazing of the pipes for the burst slug detection gear at Calder Hall. This was done by placing a short sleeve carrying copper rings in internal grooves over the ends of any two lengths of pipe to be coupled; on the application of heat from an induction coil the copper melts and the pipes are permanently joined. The coils used were shaped so that they could be placed over the sleeves in U-fashion and power was applied from a remotely sited 20 kW generator.

A high frequency current is fed through the U-shaped coil round the sleeve and copper rings inside melt, joining the two pipes permanently together



Inaccessible enclosures no bar

Induction heating can be carried out with both rotary generator and valve oscillator equipment and the company can supply either type. Output frequency of the rotary equipment varies from 2–10 kc/s. The driving motor and generator are built as a single unit using a common vertical shaft and the rotor assembly is so designed that electromagnetic centering action minimizes bearing loads. This equipment is generally used for work which demands higher power and where the lower frequency output facilitates through heating for forging and deep case hardening of shafts. For the lower powers up to 50 kW the valve oscillator type of unit is most often employed. The high voltage d.c. is obtained by mercury vapour rectifiers and supplied to one or more triode oscillator valves and tank circuit designed to produce high frequency currents varying from 200 to 450 kilocycles. It is possible with this type of equipment to house the tank circuit as a separate unit and interconnect the generator and applicator sets with coaxial feeders: this is especially handy in atomic energy fields where the brazing might have to be carried out in more or less inaccessible enclosures, particularly as the losses in the coil circuit limit the permissible length of cable to the coil.

Next move: fuel canning

The company was called on by the AEA recently to try out a method for sealing stainless steel fuel element cans. About fifty specimen cans have been completed and the Authority has placed an order for the equipment. Copper rings were again used as a brazing medium, this time in grooves round the 6 to 10° taper on the caps. After purging the can with oxygen free nitrogen the cap is fitted in, leak tightness being maintained by a rubber O-ring round the taper on the element side of the 16 gauge copper brazing ring. Current at 10 kc/s from a 25 kW air-cooled motor generator set is fed to a specially designed transfomer to which is attached a single turn solid copper heating coil surrounding the can; this brings the copper ring embodied in the joint area to brazing temperature in about 70 seconds. During heating the cap is loaded to prevent any tendency of the expanding nitrogen inside to push it out. Normally the inductor or work coil is cooled by manufacturing it from circular or rectangular section copper tube through which water is circulated, but for this particular application the coil is made from solid copper and external forced nitrogen or air cooling is employed.

Cross Section by GRACCHUS

A VERY SMOOTH job was done by NETAC for the British exhibitors at the Geneva Atoms for Peace exhibition. By common consent, I think, our contribution was certainly the most enterprising of all the national sections. Few exhibitors, for example, matched the imagination of GEC with their very clever full scale model of the Hunterston reactor ('all done by mirrors'), or Vickers' idea of a ship skeleton. It was not all gimmicks however and there was plenty of actual ironmongery, noteworthy among which were the long-secret fuel elements for the British reactors. There was also some crafty remote handling gear, not to mention a quite dazzling display of instruments of every conceivable (and inconceivable) form, I found a certain amount of grumbling throughout the show at the cruel hours —10–10 Saturdays, 10–7 others (inc Sunday)—certainly on the Saturday I looked in there were very few people about.

On NP's own stand, managing director David Rowse told me it had been very well worth while despite the hard work and I found most people thought so too. One American instrument maker I spoke to, for example, told me he'd sold every piece of equipment on his stand and was busily trying to prevent the customers taking immediate delivery. I was very much impressed by the French and German sections of the show—more by the products than the stand designs which were generally unimaginative. They made a late start but I'm sure it won't take the Germans long to catch up.

IF BRITAIN stole the show downtown it was otherwise at the scientific exhibition in the vast temporary building in the grounds of the Palais des Nations (peacocks strolled around outside quite unconcerned). It's said to have cost $M5, the American section, and it's credible. There were not just exhibits with people to show you round (they had these too, of course) but real scientists in white coats actually doing real work. For example at 9 o'clock on Monday morning Argonne staff started assembling an ARGONAUT reactor which was still in crates. By Saturday morning it had been assembled, tested and put into complete working order. This really impressed. There was also audience participation in the shape of a whole body scintillation counter. Visitors were invited to remove their shoes (throwaway slippers provided), remove any luminous watches, weigh themselves and step inside. On emerging after a few moments they were given a graph of normal count against body weight with their own reading plotted. Above the line you were muscular, below you were flabby. This produced formidable queues. Then there was the big giveaway. If you were early enough you could get the Brookhaven neutron-cross sections and other such massive tomes. But you had to be early in the morning for this, because by 10 minutes after opening the last of the lucky ones had departed, staggering with bursting briefcase and overflow clutched under each arm.

IN COMPLETE CONTRAST was the Russian section where nothing whatsoever was given away and nobody seemed to know very much about the exhibits. They've come a long way since 1955 in public relations but even now their translated captions are hopelessly inadequate. Some of the most interesting exhibits had no caption at all—Russian or otherwise. It was only because there was such a crowd round it that I spotted the model of their big thermonuclear machine OGRA. Quite a lot has been written about their ALPHA toroidal machine which is an exact copy of ZETA and I came across another case of this. They had a very fine model of a Van de Graaff machine. Now I was unable to find out whether the real thing exists or not but later I was told by the president of High Voltage Corporation that the model is a perfect replica of one of his machines—even down to a small item which is not really necessary.

Apart from Aldermaston's MINNI thermonuclear machine—not a model but a one-third working replica of the MAGGI—the AEA's stand I found rather dull and poky and really not as good as their stand at the commercial show. Both exhibits were however very well manned and everyone was very helpful.

AS FOR THE CONFERENCE—the main thing at Geneva after all—I found this all rather too much and after chatting around I think this is a pretty general impression. It's certainly nice to meet up with old friends who are now in different countries but there was really far too much on the agenda and the overall effect I found was one of blur. One thing that did occur to me was that the UK—in comparison with the US at any rate—did not always choose the best men to put over the papers. Only a few people I admit have a good platform personality but I got the impression that there's a higher proportion in America. There are of course honourable exceptions—Peter Thonemann, for example, had this big audience almost on the edge of their seats even although his paper was largely known in advance. On the other hand several British speakers with highly original stuff at their disposal unfortunately seemed to induce merely doziness. Perhaps what we need is a 'Method' course for potential speakers. This would involve the speaker convincing himself that his own contribution was easily the most important in the whole show and one likely to rock science to its foundations. On second thoughts this could be just a little tiresome if everybody got the same idea. Anyway now it's all over comes the monstrous task of reading, marking and inwardly digesting this intolerable mountain of paper. How long this will take depends on what your subject is. But metallurgy or mice it will be long.

EVERYONE who was at Geneva has a Russian story. My particular one is as follows:

SCENE: Russian section at scientific exhibition. Enter Gracchus to young Russian who speaks a little English. Let us call him Yuri.

GRACCHUS: This 5 MW power station you had working last time—what's it called?

YURI: The first atomic power station.

GRACCHUS: Yes but this is a little clumsy if you have to keep referring to it in an article for example.

YURI: But it *is* the first atomic power station.

GRACCHUS: I know, but haven't you got some abbreviation for it—like FAPS or GPU-I, for example?

YURI: No.

GRACCHUS (trying a new approach): Well where is it?

YURI: Near Moscow.

GRACCHUS: I know that, but the place must have a name.

YURI: There is a small town there.

GRACCHUS: Well what's it called?

YURI: Obninsk—but it's not really important.

GRACCHUS: Thanks (*exit to bar*).

INDUSTRIAL NEWSDESK

UK to build beryllium plant . . .

Imperial Chemical Industries' metals division is to build the first plant in Europe for the production of wrought forms of beryllium. Due to go into operation by the end of next year, it will start by making the fuel element cans for the Advanced Gas Cooled Reactor under an Atomic Energy Contract. Designs are complete and building will begin as soon as a site is fixed. The plant is intended to produce semi-fabricated forms such as rod, tube and plate, and finished machine parts.

Beryllium is a difficult metal to work with, and standards for safe handling which have been evolved and codified by the AEA will be incorporated in the new factory. Raw material will be flake or small beads, and these will be melted under vacuum in induction furnaces to produce an ingot. This is really a refining process: the cast ingot, having a large grain size and very poor workability, cannot be rolled or extruded directly in the same manner as conventional metals. It has to be made into fine powder which is then heated and compacted ('sintered') under vacuum to produce ingots, after which conventional plant can take over. ICI will not disclose the amount of beryllium which will be produced, but a spokesman says the company foresees spare capacity which may find outlets in the aircraft industry.

. . . US firm produces oxide shapes

Hot pressed and machined beryllium oxide shapes are now being produced by the US Beryllium Corporation. Initial consignments are for classified applications, but obvious uses are in reactors for moderators or reflectors, missiles for radiation windows and thermocouples, and in the electronics industry for klystron and ceramic tube parts.

Since beryllium oxide is an intermediate chemical in the production of the metal and beryllium alloys, starting material for the new shapes is withdrawn from the plant production flow. High purity beryllium oxide powder is calcined from specially processed beryllium hydroxide at 1000°C. A light, fluffy material with an average particle size of one to two microns, the powder is packed in graphite moulds for hot pressing in an induction pressing furnace. Densities exceeding 95 per cent theoretical can be attained in the hot pressing operation. After cooling, the blocks are machined into desired shapes by diamond-tipped machine tools—either pre-set or remotely controlled—operating in closed air systems. Blocks up to 12 in. in diameter and 6 in. in height are now being produced at close tolerances, and the finished product is said to be an extremely smooth, uniformly dense material.

New process tried for HTGR cans

Work on the problems involved in using graphite in the fuel elements for the High Temperature Gas Cooled Reactor has reached an advanced stage. A Harwell patented idea for reducing the permeability of graphite has been developed to a manufacturing process by the Hawker Siddeley Nuclear Power company and examples of fuel cans made by Harwell and processed by the company were on show at Geneva.

Details of the impregnation method used are not available but it is reported that it increases graphite's impermeability to the passage of gases and fission products quite sufficiently for it to be used for the HTGR fuel elements. Irradiation tests of completed elements are in progress at Harwell, using the DIDO reactor.

Other companies working on the problem are the General Electric Company—who are building the experimental HTGR—and the Union Carbide Corporation in America. They both exhibited samples at Geneva, and the GEC demonstrated the ability of its graphite tubes to remain impervious to gases at temperatures up to 600°C. Actual elements designed for the HTGR were shown by the AEA: the fuel was in the form of flat rings threaded over a graphite rod and inserted in the cylindrical hole in the graphite can. These were of an overall hexagonal cross-section and would be grouped in bundles of eight in the reactor.

Another atomic firm started

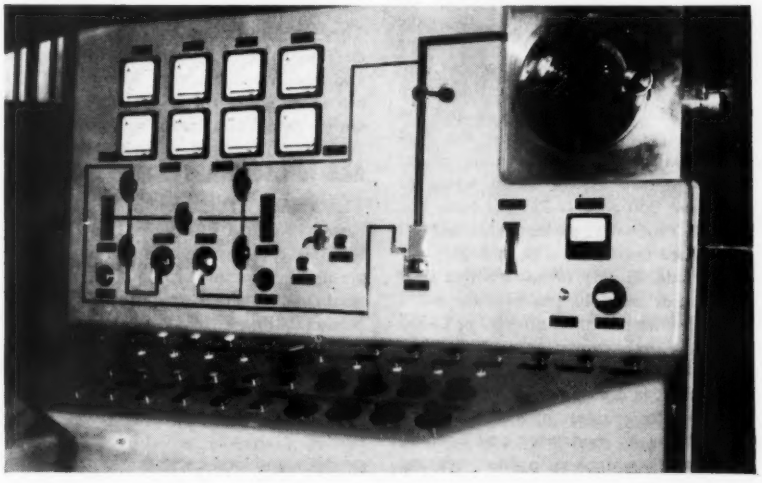
Three firms have got together to start another atomic engineering company in the UK. They are the Power-Gas Corporation, John Thompson, and Humphreys and Glasgow, and the new company—Nuclear Chemical Plant Ltd—will design and engineer process and treatment plant.

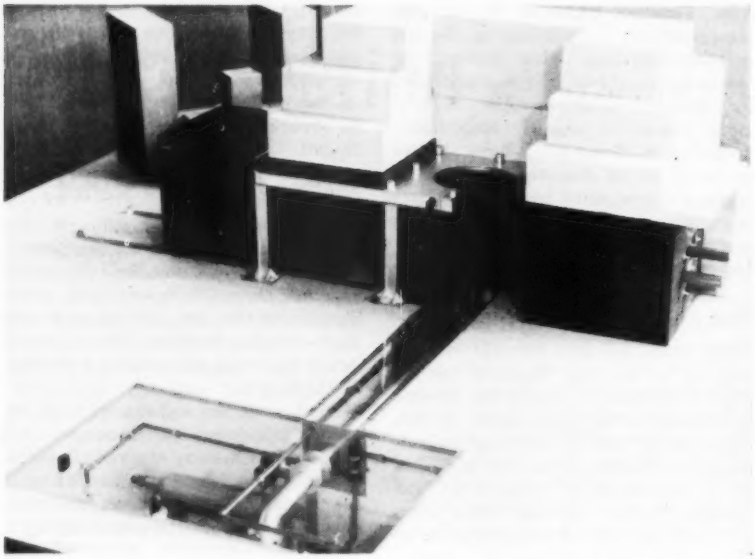
Discussions are under way about fixing a headquarters for the company and choosing the men to run it. Each of the sponsoring companies has experience in the nuclear energy industry and their resources will back the new company. It is reported that the Atomic Energy Authority is being asked to train engineers of the three companies in its Industrial Group so that they may acquire some of the AEA's knowhow in such fields as the reprocessing of irradiated fuels. This should help the new firm to cut down the initial time required for development and pilot work and get under way quickly.

JASON stirs university interest

One British and three foreign universities have already expressed strong interest in the JASON reactor—similar to the US Argonne ARGONAUT—which the Hawker Siddeley Nuclear Power company has arranged to manufacture under licence. The company is ready to go into production and say they can get a reactor on site and working within nine

ELECTRON BEAM WELDING Demonstrated on the stand of the French CEA at the Geneva scientific exhibition was this Stohr machine (see NP June p 272). In a vacuum chamber (top right) the work piece is moved slowly through an intense stream of electrons which cause highly localized melting. The UK licence is held by Edwards High Vacuum





High sensitivity to absorbing specimens is obtained in the JASON by arranging the fuel in the form of an annulus in a block of graphite. The model shows the extreme flexibility of the reactor, which is now offered to universities and training institutions

months of receiving an order. It is reported that the Atomic Energy Authority is willing to cooperate by arranging for a supply of fuel, though nothing approaching the American's fuel offer of no cash down and 4 pc/annum payment, which works out at about £1000 a year per reactor seems on the horizon.

The ARGONAUT reactor was developed by Argonne National Laboratories from the Thermal Test Reactors which have been operated for several years at the Knolls Atomic Power Laboratory, at the Hanford Fuel Works, and at Savannah River. The basic idea of these was to get high sensitivity to absorbing specimens by a combination of high flux and positioning of specimen so that the neutron which it absorbs would have been effective in maintaining reactivity. These two requirements were met by arranging the fuel in the form of an annulus in a block of graphite; this gave a high flux of well-thermalized neutrons in the central column of graphite.

The elements are contained between two aluminium tanks, one 2 ft and the other 3 ft in diameter, and the fuel plates, which consist of uranium oxide/aluminium, are assembled in boxes to give about 350 g of U-235 per box. The original ARGONAUT plates contained 20 pc enriched uranium but more highly enriched material may be used where convenient. For example, plates of the DIDO-type with uranium containing 90 pc U-235 can easily be adapted. The boxes are interspaced with graphite fillers so that the annulus is completely filled, and ordinary water passes up between the plates to act as moderator and coolant. This water, which is purified during make-up, circulates in a closed loop, giving up its heat to untreated tap water in a simple heat-exchanger.

Westinghouse forms Swiss firm

A subsidiary in Switzerland—the Westinghouse International Atomic Power Company—has been set up by the Westinghouse Electric International company. The aim is to form a close 'community of purpose' with Euratom countries, says executive vice president J. de Cubas.

The atomic consultant for Westinghouse, Major General Kenneth D. Nichols, will head the board of directors and the president is Raymond Giguet, former associate director general of Electricité de France. The new Westinghouse move will help the company to keep in close touch with three European manufacturing concerns with which it has cooperative agreements. They are the Italian Fiat group, Ateliers de Construction Electriques of Belgium and the West German Siemens. Talks are in progress for a similar agreement with a French company.

AEA to use NRC furnaces

The Industrial Group of the Atomic Energy Authority is to add to its metal treating capacity by using two 100 lb. arc-melting vacuum furnaces of the cold mould type which are based on a US National Research Corporation design. The American pattern is being modified to suit the AEA by the English company —Wild-Barfield Electric Furnaces Ltd— who manufacture NRC furnaces under licence. They will be used for both consumable and non-consumable melting.

Each furnace has it own pumping system but a common power supply is arranged, and three rectifiers are incorporated. Output is such that a 4 in. ingot can be melted in each furnace simultaneously or a 6 in. ingot in one furnace, with a 50 pc reserve of power in either case.

Several industrial concerns have current orders for furnaces. One is to be used by Babcock and Wilcox for a beryllium project. It is a vacuum induction type and is being specially engineered by Wild-Barfield to handle this metal. Capacity will be about 15 lb. Another vacuum induction furnace to be delivered towards the end of the year will be employed by the English Electric company for uranium.

Vaughan named NPPC director

Roger Davison Vaughan, chief engineer of the Nuclear Power Plant Company and head of the team which designed the 300 MW Bradwell nuclear power station, has been named a director of the firm at the age of 35. An Australian, he started his engineering career in Melbourne twelve years ago designing plant for the manufacture of antibiotics. His first job in the UK was with C. A. Parsons and he moved up inside three years to the position of chief engineer working in Calcutta. He left the company in 1954 to spend a year at Harwell picking up a basic knowledge of nuclear work and joined the NPPC as chief engineer three and a half years ago.

R. D. VAUGHAN led Bradwell designers

AGR vessel, turbines ordered

The Atomic Energy Authority has now ordered the pressure vessel and turbine for their Advanced Gas Cooled Reactor. To be built by Whessoe, the pressure vessel containing the core and moderator will be a 53 ft 6 in. vertical cylinder of

about 21 ft dia with hemispherical top and bottom heads. It will be constructed from notch ductile steel plate of considerable thickness with the top head perforated by a large number of closely pitched charge tube and control rod standpipes for refuelling and controlling the reactor.

The internals are most complex. They include the support of the heavy core and graphite moderator and the shielding material. The internal baffles will be arranged in such a manner that the relatively cool inlet gas sweeps the entire pressure vessel shell: hot gas will be collected from the reactor channels and passed out of the reactor through an inner concentric duct so that it will not be in contact at any point with the vessel shell.

The turbine will be manufactured by the English Electric Company to be ready for commissioning in 1961. Power of the steam turboalternator set will be 33 MW and the contract includes condensing and feed-heating plants with auxiliary apparatus. The alternator will be air-cooled, the turbine of the two-cylinder impulse reaction type, operating at 3000 rpm with steam at 650 psig and 850°F.

Capenhurst boron plant moved

Low temperature distillation plant at the Atomic Energy Authority's Capenhurst production factory has been moved to 20th Century Electronics' works in Surrey as part of a ten year agreement signed with the firm for the manufacture and supply of stable Boron-10. Dismantling and re-erecting the columns and processing plant took less than ten days all told and was carried out by the company's staff with advice from AEA experts. The two 75 ft four ton columns, which normally hang from a steel pylon, were transported by road from Liverpool to London.

The firm is licensed to use the AEA patents in connexion with the new project and can benefit from this knowhow commercially as they have permission to sell surplus B-10 and B-11 providing the Authority's own requirements are satisfied.

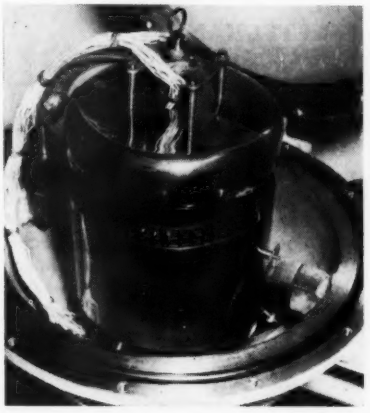
Boron-10 is a costly material—ten times as expensive as gold—but is one of the most efficient neutron absorbers. Though not available in time to be used for the Dounreay fast reactor control rods, it is employed in the US Enrico Fermi plant and is likely to be a key material in future fast reactors as well as nuclear-powered submarines and aircraft. The plant installed at New Addington is believed to be the largest in the world.

Now working at New Addington these two 75 ft distillation columns form part of the world's largest plant for producing Boron-10

More research on Pu, graphite

A laboratory graphitizing furnace developed from an original Harwell Design has been completed by Spembly Ltd, at Chatham. It has been sent to Harwell for testing and is eventually bound for a Hull institution, where it will be used for graphite research. The heating element is graphite and it will operate—in argon or vacuum—at temperatures up to 3000°C using a 20 volt 1000 amp single phase supply.

Another project is the manufacture of calorimeters and furnaces for plutonium alloy research at Harwell, two of which have been made so far. Each calorimeter and furnace employs over 109 similar junctions in 0·005 in. dia chromel/alumel wire, taking the form of three 24 junction thermopiles, and the remainder are single junction thermocouples.



Designed for plutonium alloy work this calorimeter and furnace uses 6 heater elements for isothermal balancing and one very small element for heating the specimen

IN BRIEF

Gas turbine move Armstrong Siddeley Motors Ltd is to manufacture in the UK the range of gas turbines produced by Clark Brothers company, which is part of the US Dresser Group.

New Belgian company Métallurgie et Méchaniques Nucléaires has been established by Métallurgique de Hoboken and Fabrique Nationale d'Armes de Guerre. Purpose will be to carry out metallurgical research and development for production of fuel elements and reactor cores.

Capenhurst The Industrial Group of the AEA has ordered a Mark 2 *Deuce* computer for the Capenhurst diffusion plant. Main use will be for studying plant performance and indicating optimum production schedules, though it will also be used for research work.

Nuclear work on show Examples of new types of fuel elements, reactor models, and films will be shown by the AEA at the Fuel Efficiency Exhibition at Olympia from September 24 to October 3. Small displays illustrating the UK atomic energy industry were staged by the Board of Trade at the International Autumn Trade Fair in Vienna from Sept 7–14 and St Erik's Fair in Stockholm Aug 30–Sept 14.

HVEC sale to Swiss The US High Voltage Engineering Corporation has sold two Van de Graaff particle accelerators in Switzerland. A 6 MeV model will be installed at Zürich University and a 3 MeV at the University of Neuchatel.

In the second edition of the NUCLEAR POWER YEAR BOOK AND BUYERS GUIDE, just published, the name of Nuclear Enterprises (GB) Ltd was omitted from the product classification *Scintillators–plastic* although it appears correctly under other forms of scintillators. Nuclear Enterprises claim to supply 95 pc of plastic scintillators in the UK.

Plessey Nucleonics Ltd have informed us that the performance data used in their recent announcement regarding their new range of Neutron Detectors was reproduced by kind permission of the AERE, Harwell.

The Corblin compressors mentioned on p 430 of our Atoms for Peace preview in the September issue can deliver oil-free any gas up to 1000 atmospheres and not 1000 psi as stated.

New Product Survey

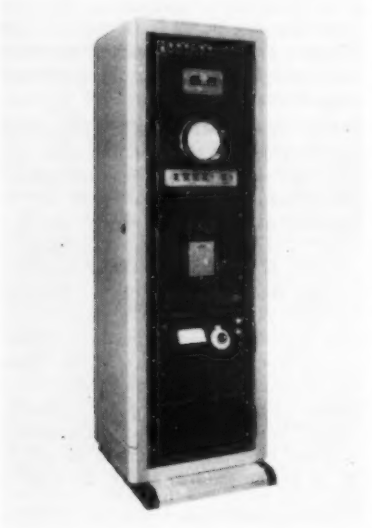
PLANT · EQUIPMENT · INSTRUMENTS · MATERIALS

MULTI-CHANNEL KICKSORTER

New Mullard model

A new 100-channel pulse spectrometer (or 'kick sorter') was shown for the first time at Geneva by Mullard Ltd. Used with a proportional detector and standard pulse amplifier, its applications include study of fundamental nuclear phenomena, identification of isotopes and, in conjunction with neutron time-of-flight equipment, measurement of capture and scatter cross-sections. In the medical sphere it may be used for multiple radioactive tracer experiments and for measurement and identification of the radioactive 'burden' within the human body.

The L332 is based on a Harwell design and is intended for integration with complete systems of instrumentation. Pulses from a proportional detector are sorted and counted according to their relative amplitudes into any one of 100 channels, where they are stored in a magnetic memory. Since each channel represents a particular energy level the data recorded in the memory provides a histogram showing the relative abundance of radiation at each of 100 energy levels within the spectrum under observation. This information is presented on a 6 in. diameter c.r.t. as a continuous linear analogue display of the spectral curve, the display being available both during and after the counting period. Seven full-scale ranges are provided, selected by a switch. A direct read-out of the number of counts registered in a particular channel is also available, from 'in-line' neon digital indicators. Provision is made for connecting a remote control device to operate the read-out, which is non-destructive, the memory retaining all information until it is deliberately erased by a protected master switch. The memory is also protected in the event of a mains failure.



Based on a Harwell design, the spectrometer uses a ferroxcube magnetic memory matrix storing over 65,000 counts

The memory system is a magnetic matrix of 100 by 16 Ferroxcube cores, giving each channel a storage capacity of 65,536 counts. The basic input range of the spectrometer is from 0·5V to 10V, each channel having a width of approximately 0·1V. Up to 30V back bias may be applied, giving a total coverage equivalent to 400 channels.

Maximum counting rate is limited only by the permissible percentage of lost counts due to the deadtime, which is constant at 250 microseconds for accepted pulses, with rapid rejection of oversize pulses. A gating circuit incorporated in the input controls the pulse stream to prevent errors due to a fresh pulse arriving before the preceding one has decayed. Uniformity of channel-width is better than 1 pc and stability of channel positions is better than 10 mV over the basic input range, or 20 mV with full backbias. Random jitter is less than 3 mV (basic range) or 20 mV (full backbias). The spectrometer operates from single-phase mains supplies of 200-250V, 45-65 c/s and, due to the extensive use of transistors, its consumption is only 300 watts. It is stabilized against variations in the mains voltage of up to ± 10 pc.

Tick No 195 on reply card

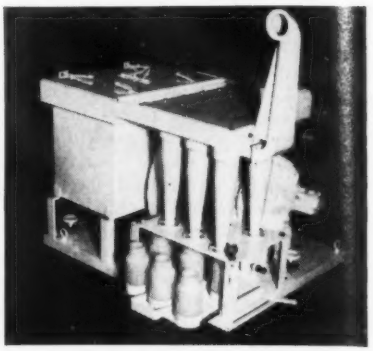
MOBILE SWARF COLLECTOR

Vokes unit for AEA

On the stand of Vokes Ltd at Geneva was shown for the first time a mobile swarf collector for use in machining radioactive materials. Developed for the UKAEA, the unit operates on the vacuum cleaner principle. It is confined to a cell in a laboratory where radioactive material is processed.

The collector is operated by remote control from outside the cell and is required to handle heavy dust concentrations, yet maintain absolutely clean air at the outlet. The contaminated air is sucked into an inlet and by cyclonic action, the heavy particles are deposited into polythene bottles, the remainder passing through a Vokes' high temperature 'Absolute' filter.

As gamma radiation is to be encountered, a prime necessity was care in the choice of materials, particularly in respect of the final filter. Only glass paper was suitable and the sealing compound was carefully investigated to ensure there would be no breakdown.



The swarf collector is completely self contained and remote controlled. Heavy particles are removed by cyclones and collected in bottles

The mobile swarf collector is completely self contained with fan and motor. Everything has been designed for ease of servicing and replacement by manipulators. Capacity is 200 c.f.m. and fan power available, 20 inches of water.

Tick No 196 on reply card

DIGITAL INDICATOR

Edge illumination

A common disadvantage of some types of digital indicator is that the angle of view is severely limited by the overall thickness of the stack of plates, which is necessarily great because of the comparatively large dimension of the lamps. This disadvantage is claimed to have been overcome in the KGM *Multi-Indicator* by utilising the total internal reflexion characteristic of bent Perspex sheet; the light from the illuminated edge is conveyed round the bend without transmission through the surface of the plate. The plates are bent over at right angles at one end and the tails thus formed are inserted into individual slots behind which are the light sources (Atlas midget panel lamps). This construction permits the plates to be tightly packed together forming a stack only slightly more than ¼ in. thick and thereby permitting the rear plate to be viewed at a very wide angle. A further advantage of this construction is that the lamps are easily accessible from the rear. The KGM *Multi-Indicator* is

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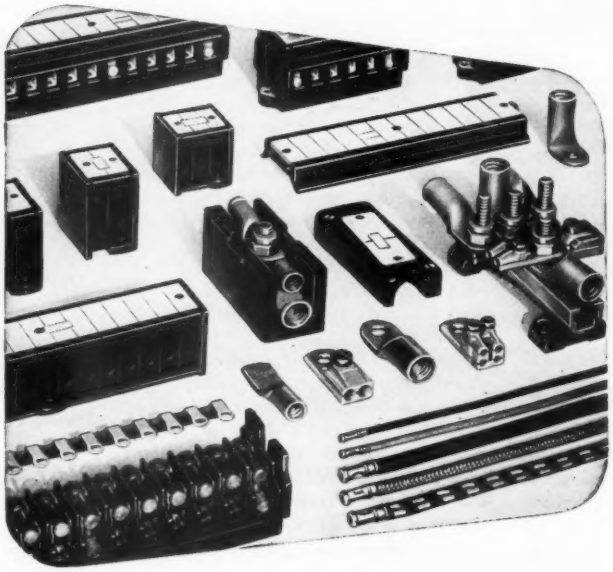

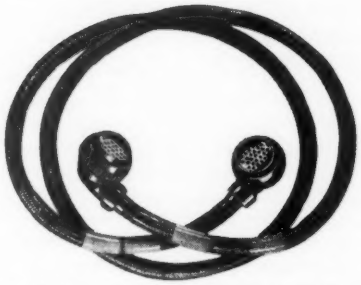

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designed for fitting into panels of any thickness either singly or in banks and its size has been kept as possible commensurate with a suitable

The characters can be engraved in small dots as shown or as continuous lines

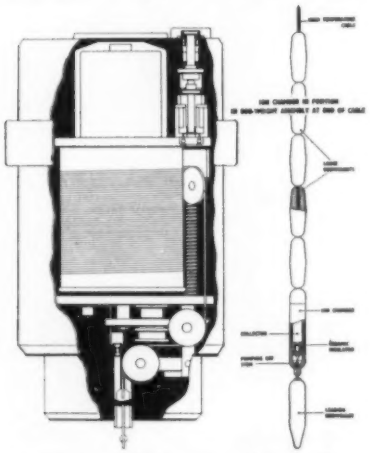
size of display. The engraved characters are readable at a distance of twenty feet or more depending upon room illumination. Typical applications include: counters, digital voltmeters, timing systems and clock displays.

Tick **No 197** on reply card

REACTOR FLUX SCANNER

Ion chamber method

Shown for the first time in public at the Geneva Atoms for Peace exhibition was the new Plessey flux-scanning equipment. This enables rapid measurement of the



In a gas-cooled reactor the winding head is installed at the top of a fuelling standpipe and the ion chamber lowered through the desired channel

neutron flux distribution within the core of a large gas-cooled reactor. The flux is measured by a small neutron-sensitive ionization chamber which is lowered through the core on the end of a high temperature flexible cable from a winding head installed in a standpipe on the pile cap. The output of the ion chamber is displayed on a chart recorder. A number of winding heads are installed across the pile cap and each head in turn is operated from a control panel adjacent to the recorder. When not in use the ion chamber is raised by winding up the cable, to a position on the base of the standpipe.

This ion chamber technique may be applied to reactors with a wide variety of core designs, using either rigid or flexible connectors.

Tick **No 198** on reply card

CONTINUOUS AIR SAMPLER

New French design

The French company, Construction Radioélectriques et Electroniques du Centre (CRC, for short), are marketing an interesting air sampler, which records continuously alpha, beta and gamma activities (Type ASP 249). The sample is drawn into the apparatus by suction and deposited on a travelling filter paper and the activity—alpha or beta, or alpha plus beta plus gamma—measured by a semi-proportional counter with a thin mica window and registered on a chart recorder.

Sensitivity of the instrument is sufficient to detect levels below the lowest tolerances (five alphas from radium or plutonium, per cubic metre of air). It can also record radon and thoron levels. The sampler is completely self-contained and is trolley mounted. It was shown at Geneva.

Tick **No 199** on reply card

RESEARCH AND ISOTOPE REACTOR

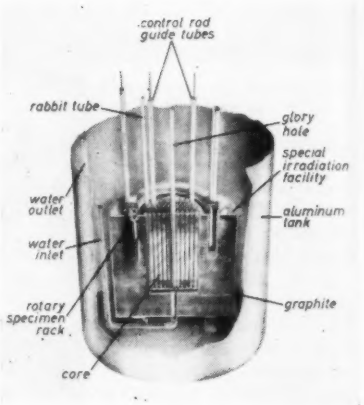
GA's TRIGA at Geneva

One of the working reactors at the Geneva scientific exhibition was the TRIGA, manufactured by General Atomics Division of General Dynamics Corporation. With a normal output of 10 kW and useful flux of 10^{11}, the reactor is of the solid homogeneous water-cooled type. Fuel-moderator elements are of zirconium hydride containing 20 pc enriched uranium, clad with aluminium. Critical mass is about 2 kg (70 elements) and the maximum excess reactivity 0·5 pc. A graphite reflector about 1 ft thick surrounds the core on the sides and bottom: it is sealed in a welded aluminium can. Top shielding is provided by six inches of graphite included in each fuel element.

The core is contained at the bottom of a 20 ft deep, 6 ft-dia well and is covered by 16 ft of water. A small refrigeration unit cools the circulating water which is also continuously demineralized.

Extreme safety in operation is claimed for the reactor because the design of elements is such that a prompt negative coefficient of reactivity obtains at all times. Core lifetime based on 10 kW, 40-hour week, is estimated to be 20 years.

The two main purposes of TRIGA are isotope production and training. An interesting isotope production rack is included, in which 40 specimens may be irradiated. These circulate round the core and are extracted and inserted one at a time through a single tube. A pneumatically-operated rabbit tube is provided for isotopes with very short half-



Costing about the equivalent of £50,000 the reactor is intended for training, research and isotopes—hence TRIGA

lives and several other irradiation facilities are also included. For educational purposes, a great variety of experiments may be arranged, including such things as measurement of absorption cross-section by the pile-oscillator method.

Tick **No 200** on reply card

RADIATION MONITOR

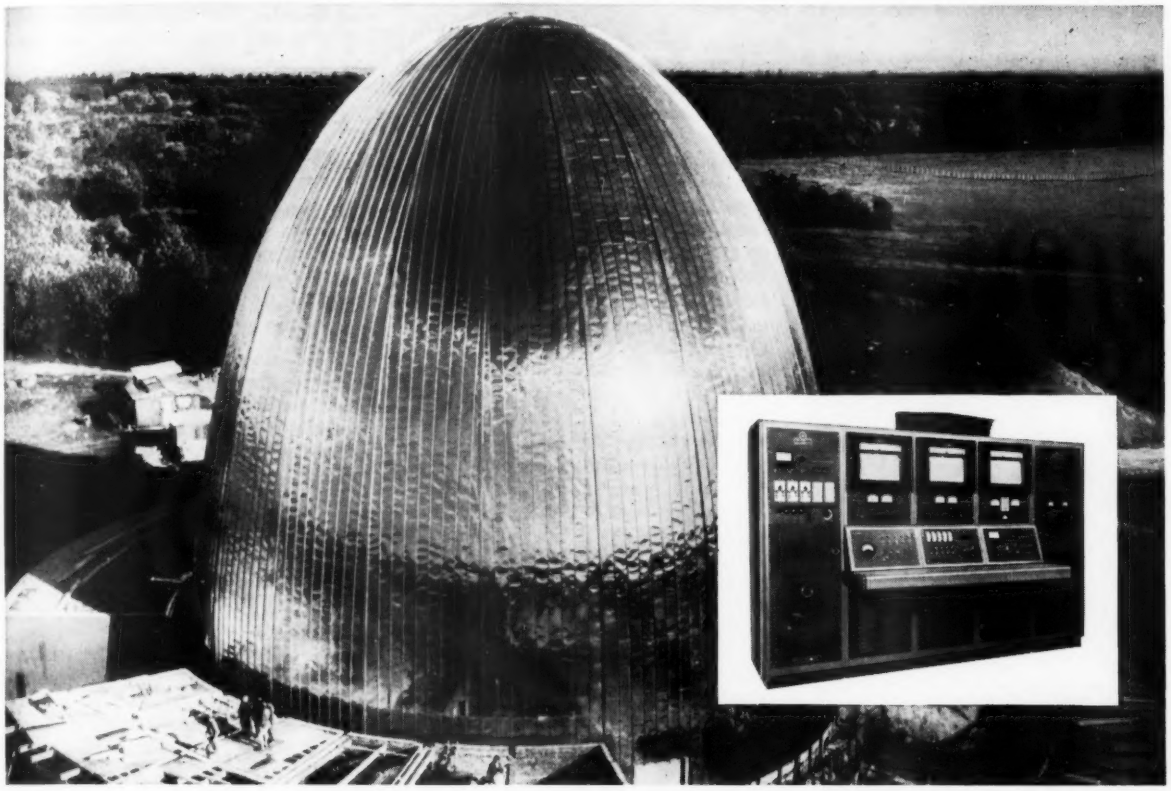
For high level testing

The *Hot Spot Monitor* by Avo Ltd, is a very light portable battery operated instrument with a remote ion chamber for the measurement of radiation intensity in close proximity to high level sources of beta and gamma radiation.

The ionization chamber is held by the operator at the remote end of an extending rod and is constructed of suitable 'air-wall' characteristic materials and has a volume of 150 cm³. The indicator unit is easily carried by the operator and radiation is observed

Peaceful nuclear landmark: Rising 100 feet from the flat farmlands near Munich, Germany, is this aluminum-sheathed nuclear reactor, main laboratory instrument of the nuclear research centre at Munich Technical University. Designed and built by AMF, the 1,000 kilowatt pool-type research reactor is the first to become operative in Europe under President Eisenhower's "Atoms for Peace" programme.

(Inset) The control console of the AMF-built Munich Research Reactor. The reactor will be used to train students in nuclear research, primarily in the field of solid state physics. It will also produce radioisotopes for use in medical and industrial research, as well as for use by the University itself and other educational centres.



FIRST AMONG RESEARCH REACTOR BUILDERS–

AMF creates new tool for atomic probe!

With the opening of Munich Technical University's new atomic research centre, AMF – the leader among research and training reactor builders – now has three installations in operation, with twelve more in various stages of design and construction. In fact, *AMF is today building more than twice as many research and training reactors* as any other company in the world!*

In the field of atomic power, AMF Atomics works in close cooperation with Dr. Walter H. Zinn and his General Nuclear Engineering Corporation, as well as with Mitchell Engineering Ltd. of London. Together they have developed a number of advanced power reactor designs which offer great promise for the economic production of electricity in areas in which conventional fuel costs are high.

Ship propulsion is a particular application of nuclear energy in which AMF has specialized experience. Under a Nuclear Energy Programme sponsored by a joint committee of the U.S. Maritime Administration and the U.S. Atomic Energy Commission, AMF recently designed a Closed Cycle Boiling Water Reactor System for propulsion of a 38,000-ton tanker. The AMF design was approved by the joint committee and has now become the basis for a construction programme.

Dockside refueling of a nuclear-powered vessel presented a knotty problem which AMF successfully solved. For example, the complete refueling of the nuclear submarine, "Seawolf," is handled by such AMF equipment.

Eminently qualified in all aspects of nuclear ship propulsion, AMF is prepared to conduct feasibility studies, design power plants, manufacture all or part of the components, furnish consulting and engineering services, as well as supervision during installation, loading of fuel and sea trials.

In addition to their reactor design and construction activities, AMF Atomics has also taken the lead in the development of reactor control-rod drives, remote material handling equipment and other specialized nuclear components. Such AMF equipment is now in service throughout the world.

For a complete reactor facility, either for training, research, power or ship propulsion ... for specialized control and handling equipment ... for authoritative assistance at any stage of *your* atomic energy programme ... AMF nuclear design and development engineers will be glad to work with you on your specific problems.

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Tick No 68 on reply card for further details

directly on a 5 in. logarithmic scale. Readings can be obtained from 0·1 r/h to 500 r/h.

With an instrument of this type it is not necessary to measure down to tolerance levels, i.e. 7·5 milliröntgen/h, as the operator can stand at a safe distance from the source of radiation. A prototype instrument was shown at Geneva.
Tick **No 201** on reply card

The Hot Spot monitor uses a ·00025 in. aluminized Melinex window which is easily replaceable

THERMOCOUPLE RECORDER

New 500 point instrument

A new multi-point thermocouple recorder, which provides a permanent printed record of the temperature from any one of up to 500 points, the time at which it was taken and the channel identification, is being produced by Savage & Parsons.

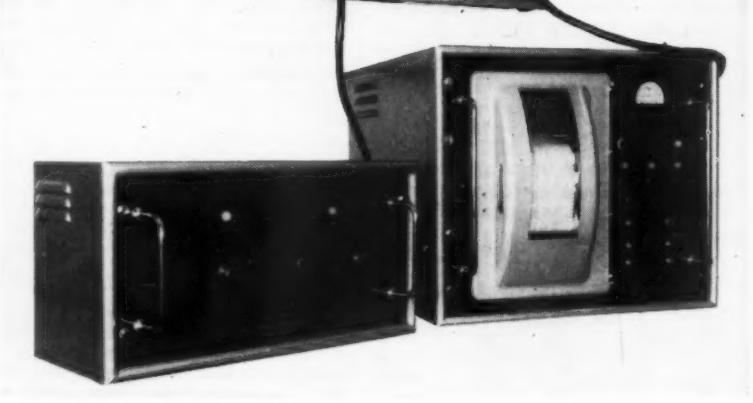
The recorder consists, basically, of two units. One contains a precision voltage supply for the thermocouples, and the printing head, motor-driven slidewire and servo equipment. The other unit is an extension box housing 50 thermocouple connexions, selector switching and provision for a 'cold junction oven.' Additional extension boxes—each with 50 thermocouples—can be added, as required, to give up to 500 points.

The maximum temperature range with which the equipment can deal is between 800°C-1000°C, depending on the type of thermocouple used. Measurements are recorded on a 3-in. strip chart, capable of accommodating a total of 3000 readings on its 50-foot length. The maximum rate of printing is approximately 100 measurements a minute, each measurement comprising the three variables (time, temperature and channel).

On the Savage & Parsons stand a preproduction model was shown attached to a small model of a reactor core, as one of the expected uses is the continuous reading of reactor-core temperatures.

An added advantages is that by employing an alternative extension box, with resistance strain gauges instead of thermocouples, the equipment can be used as a multi-point static strain recorder.
Tick **No 202** on reply card

The recorder on the right contains precision voltage supply against which the thermocouples are balanced, the printing head and motor-driven slidewire equipment. Unit on left houses t/c connexions, selector switches and cold junction. Top is the junction box



IN BRIEF

Atomic lights Phosphor-coated tritium-filled tubes for emergency lights in aircraft has been produced in prototype form by US Radium Corporation. Depending on brightness required they can last 25 years and are visible at about 100 ft. One use is for emergency exists.
Tick **No 203** on reply card

Internal welder For automatic welding of internal seams in narrow vessels Quasi-Arc Ltd have introduced a new High Lift Internal Welder. It can work inside vessels of 2 ft 6 in. to 10 dia and up to 10 ft long.
Tick **No 204** on reply card

Insulation tester The Mk III portable flash tester by Gresham Transformers Ltd incorporates several improvements over the Mk II model and is now in full production. It's suitable for testing up to 2500 volts a.c.
Tick **No 205** on reply card

Safety lock-up valve Mason-Neilan type 76 lock-up valve from Crosby Valve & Engineering Co Ltd locks the gate in its last position if a failure of the air supply should occur. It can be set to lock at any pre-set pressure and is suitable for control processes which are relatively stable. In this way a complete shut-down can be avoided.
Tick **No 206** on reply card

End-window GM tubes A large range of these is now available from Nucleonic Corpn. of America. It includes detectors with bismuth mesh cathodes that provide high sensitivity to gamma—especially to those from I-131.
Tick **No 207** on reply card

Gas regulator New types of single-stage regulator for CO_2, Acetylene, Oxygen and Propane have been designed by British Industrial Gases Ltd to meet needs of shipyards, constructors etc. Designed for low cost, they are suitable for all standard welding equipment.
Tick **No 208** on reply card

High speed fastenings Widely used in the US, the Avdel Lockbolt is available in the UK from Aviation Developments. Unskilled man can fix up to 30 a minute using special gun.
Tick **No 209** on reply card

Corrosion-proof handrails Forged stanchions and extruded tubing in Noral alloy, polished and anodised, from Northern Aluminium. Needs no painting or maintenance.
Tick **No 210** on reply card

Muffle furnace Three sizes for laboratory or toolroom from Metalectric Furnaces. Muffle can be removed through door without disturbing insulation.
Tick **No 211** on reply card

New alloy J. Stone and Co (Charlton) offer magnesium-base alloys containing silver, rare earth metals and zirconium. Known as MSL alloys they have good creep resistance at high temperatures.
Tick **No 212** on reply card

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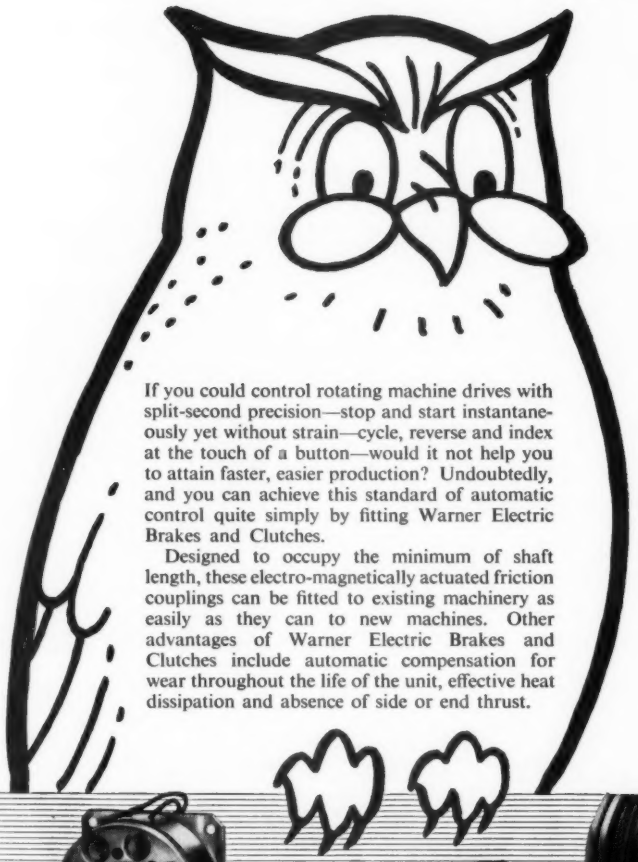
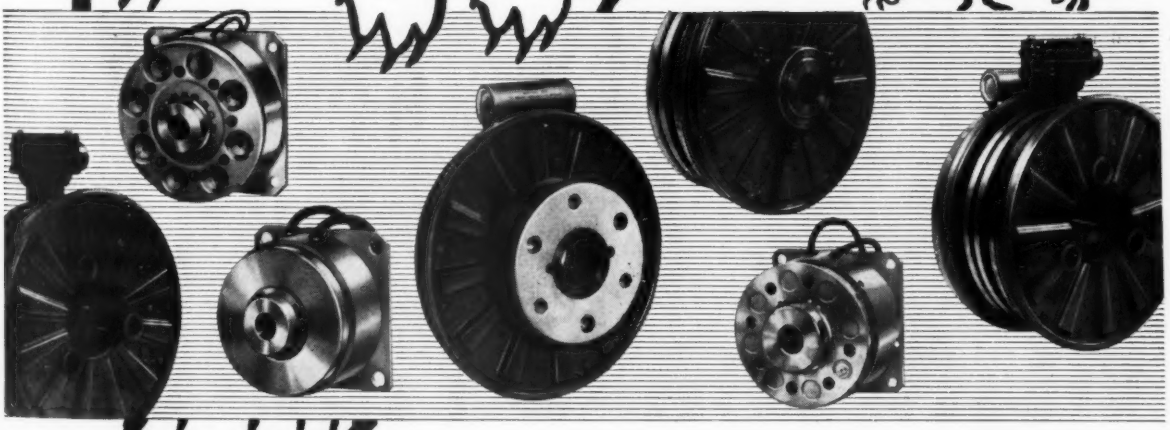
get wise to modern methods of machinery control



If you could control rotating machine drives with split-second precision—stop and start instantaneously yet without strain—cycle, reverse and index at the touch of a button—would it not help you to attain faster, easier production? Undoubtedly, and you can achieve this standard of automatic control quite simply by fitting Warner Electric Brakes and Clutches.

Designed to occupy the minimum of shaft length, these electro-magnetically actuated friction couplings can be fitted to existing machinery as easily as they can to new machines. Other advantages of Warner Electric Brakes and Clutches include automatic compensation for wear throughout the life of the unit, effective heat dissipation and absence of side or end thrust.



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They said...

points from papers, speeches, conferences

WORLD POWER CONFERENCE

A BIG PROGRAMME of both high temperature gas-cooled and fast reactors in the UK would need more plutonium than the early nuclear power stations could produce before about 1970, and it will probably be worth while to use

J. A. JUKES
It would work in theory

some enriched fuel from the diffusion plants to get the system going sooner and faster. In a paper on the Economics of Nuclear Fuels at the Canadian sectional meeting held in Montreal from September 7-11, J. A. Jukes and J. K. Wright of the AEA emphasized that a large installation rate of HTGR's—say 1000 or 2000 MWe a year—would require several tons of plutonium (or U-235) each yeear. Although in theory it would be possible to develop a balanced programme of reactors in which the introduction of various types was so phased that plutonium produced just equalled enriched material required, this would lead in practice to a long initial period in which natural-U reactors were used exclusively, and the introduction of enriched systems would be slow.

Another economic problem will be posed by the use of expensive canning materials like beryllium and zirconium. It is probable that in both cases the first production versions of the fuel elements will prove costly and will involve the rejection of some proportion of those manufactured. Even after use there is the possibility that irradiated fuel elements may have to be segregated according to canning material or fuel enclosed which will step up costs. For uranium at various levels of low enrichment it may be necessary to run the chemical processing plant on a batch basis, cleaning it out between runs.

'Germany determined to get in'

West Germany has every intention of building and exporting its own atomic power stations and considers that this constitutes an important objective for exports in the future, said Prof Dr-Ing K. Wirtz, of the reactor station and technical high school, Karlsruhe, in a paper on nuclear power in West Germany. Procuring research reactors abroad was merely an emergency measure, he stressed. The real aim was the development of research and power reactors in Germany. Conventional power stations have always been exported, and manufacturers—especially large electricity concerns—cannot afford to ignore the new development. 'At the same time,' Professor Wirtz went on, 'it must be realized how difficult it is to introduce the requisite originality into German work when the simple lines of reactor development have already been undertaken in foreign countries—often with considerable outlay.' Every attempt in this direction encounters big financial risks in addition to the technical difficulties. Nevertheless, five groups have announced willingness to take part and it is intended to develop several different types of power reactor independently by 1965. These are: (a) graphite moderated gas cooled using natural-U (b) heavy water moderated and cooled also natural-U fuelled (c) light water moderated and cooled using slightly enriched U. All these would be 100 MW capacity, and in addition a 15 MW high temperature gas cooled power experiment employing enriched-U would be built. The Federal Minister for Atomic Energy is holding out the hope of financial support for firms and future customers who wish to participate.

Reviewing the capacity of German industry to carry out its own atomic programme, Professor Wirtz said natural uranium and heavy water will be obtained from inside Germany, supplemented by imports where necessary. The graphite capacity is adequate and special materials such as zirconium can be produced. The manufacture of fuel elements, which is already possible on a small scale, is to be expanded and a plant for reprocessing fuel elements at the rate of 300-500 tons a year was planned—though initially Germany will take part in the OEEC project. In addition priority is to be given in the programme up to 1965 for the building of an institute to study the metallurgical and engineering problems of using plutonium. 'It is not intended,' he concluded, 'that the programme up to 1965 shall have any noticeable effect on energy supply. It is independant of any imports of atomic power stations in the meantime and is meant only to promote the development of German power reactors.'

J. K. WRIGHT
Fuel elements will be dear

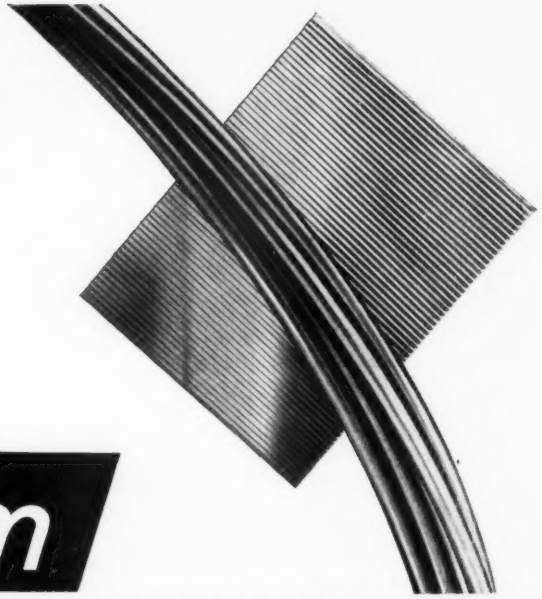
Radical changes ahead?

The metallurgical problems involved in working at gas temperatures of 550-600°C in future graphite moderated gas-cooled reactors could be so severe that it might be best to scrap the present system of plant layout and try a radically different approach. Sir Christopher Hinton and L. Rotherham from the CEGB advanced this view in their paper 'A review of the future of nuclear reactor systems.' They emphasized that the high temperature gas-cooled reactor—which will have to use ceramic fuel canned in some such material as beryllium to achieve much higher ratings and burnup—will need 'very great' technical advances, and it would be a mistake to assume that these will be confined to fuel elements. Though this is the main problem gas pressure will have to be raised to get the higher ratings, and 'we shall be seeking to do this at a time when the conditions for the pressure shell are being made more difficult by the fact that gas outlet temperature will be between 550° and 600°.

This might be dealt with by the use of alloy steels for the pressure vessel and gas circulating ducting. 'But it seems

Zirconium offers a combination of useful properties very attractive to the nuclear engineer.

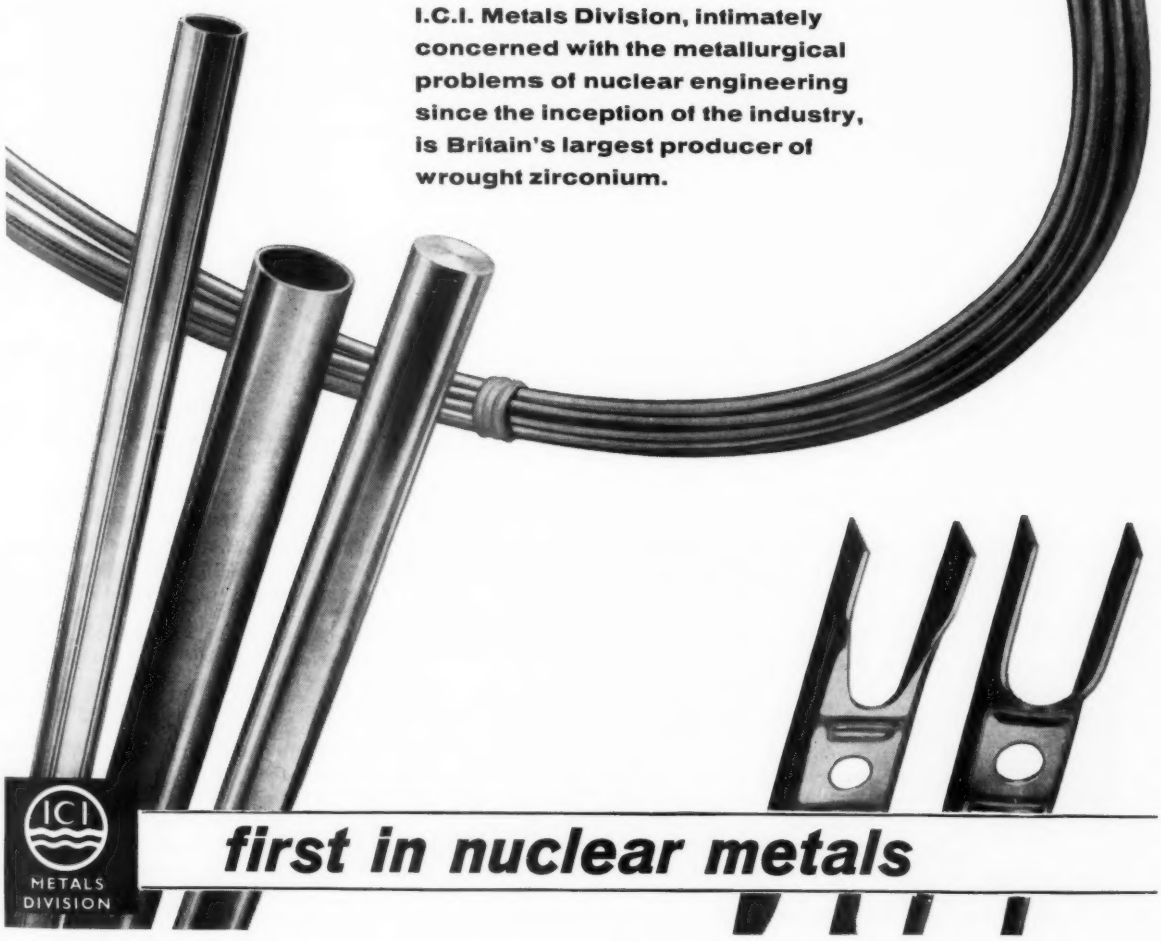
With high mechanical strength, low neutron absorption and good compatibility with uranium as natural assets, zirconium can be alloyed to provide in addition good corrosion resistance to water at high temperatures, or to carbon dioxide.



Zirconium

THE SPECIALIST'S ANSWER TO A SPECIALIST'S PROBLEM

I.C.I. Metals Division, intimately concerned with the metallurgical problems of nuclear engineering since the inception of the industry, is Britain's largest producer of wrought zirconium.



ICI METALS DIVISION

first in nuclear metals

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probable,' they said, 'that a more elegant solution lies along the lines of a completely new conception in the layout of the plant. Patents have been taken out in the United Kingdom for an integral type of reactor and heat exchanger which obviates the problems of duct design and ensures that the pressure shell is not subjected to the top temperature of the coolant but only to the temperature of the gas re-entering the reactor core.'

Other difficulties in achieving the type of design envisaged include the possibility that chemical reactions between the moderator and coolant may be seriously accelerated at the neutron intensities which will exist in so highly rated a reactor. These and other similar problems are being studied and the work will be further developed when the advanced prototype has been built.

SGR may be a success in America

In a review of present reactor systems the authors pointed out that a prospective buyer for a land-based reactor in the western world would give serious consideration to only two types —the graphite moderated gas cooled developed in Britain and the pressurized water system preferred by America. Liquid cooling would give higher fuel rating than gas cooling at any stage of reactor development simply because liquids are better conductors; but on the other hand it will always be possible to get higher temperatures by using gas since top temperatures are limited not merely by metallurgical problems at the centre of the fuel element but also by problems of attack on the can and other parts of the reactor by the coolant. Whatever the coolant these problems become more acute as temperature rises but it is always possible to select gases which are less reactive than any available liquid. An increase in fuel element rating at any top temperature decreases capital cost, but raising the top temperature in the heat cycle reduces the capital cost not only of the reactor but also the heat exchangers, turbines etc. 'It therefore seems that increases in top temperatures will be more important than increases in rating in reducing capital operating costs, which makes the gas-cooled type still the most promising line of development for land-based reactors.'

There may be specialized fields—ships are an example—where high ratings will be of greater importance than high top temperatures and in these fields the liquid-cooled type 'will be important.'

At present the only system which appears to offer some prospects of competing with graphite-moderated gas-cooled and PWRs for large land-based power stations is the graphite-moderated sodium-cooled reactor. But though studies suggest that it could produce power more cheaply than the gas-cooled type, this goal could only be achieved after construction first of a prototype and then, after a reasonably long period of operation, the building of an industrial plant. It could therefore hardly be in operation before 1965 and costs 'appear to be above those we predict for the gas-cooled type at that date. This is why the Atomic Energy Authority has decided not to devote attention to it—but this does not mean that it might not be attractive in the US.' It demands a fairly high degree of enrichment and the low cost of this in America 'might swing the pendulum.'

Waiting for beryllium

It may well pay to hold back gas outlet temperatures to achieve greater savings in capital cost and extra reliability until a new canning material permits a really significant advance in temperature; this suggestion was made in the paper on 'Trends in design of large British nuclear power stations,' by H. West and A. L. Shaw of the AEI-John Thompson Nuclear Energy Company. Whereas in coal-fired stations the biggest need for improvement is in thermodynamic efficiency, for nuclear power the main design attack should be on specific capital cost with steam cycle improvements regarded rather as an additional—though highly desirable—bonus.

To increase heat output without materially affecting fuel element design performance 'quite spectacular' results can be obtained by such means as increasing core diameter by 10 pc, reducing lattice pitch (thus increasing the number of channels) stepping up coolant gas pressure by about 40 pc, and raising blower power slightly. This has been done in the Hinkley Point design and it increased net electrical output by 60 pc. 'It should be noted,' the paper goes on, 'that the designers accepted a lower overall thermal efficiency of 25·5 pc. They aimed at achieving a nice balance between capital cost savings and overall thermal efficiency.'

Compared with Hinkley Point the next round of nuclear power stations in the UK is 'unlikely' to show very great improvements in technical performance. They will represent a stage of consolidation and general detailed design improvements pending the introduction of a new canning material. It is possible that beryllium will be used initially in reactors commissioned in the middle 60's and developed to operate at higher temperatures towards 1970. 'However' say the authors 'we should be doing a disservice to prospective users of nuclear power if we were to be over optimistic about reductions of specific capital cost in the next two years.'

BRITISH ASSOCIATION

Annual meeting Aug 27–Sep. 3

Nuclear rockets in 10 years?

The use of nuclear power for rocket propulsion might be feasible when the limits of development with chemical fuels are reached in about ten years time, said J. Edwards, of the Atomic Energy Research Establishment, Harwell, recently. Presenting a paper on Nuclear Propulsion — prospects for ships, aircraft and on land, to the meeting of the British Association, he disclosed that a practicable method of propulsion could be obtained by using the

J. EDWARDS
Use reactor coolant

reactor coolant. This, stored in a liquid form, would be passed through the reactor core, thus being heated to a suitable temperature, and then expanded out through a convergent-divergent nozzle. A low molecular weight material such as hydrogen would probably be used and to get worthwhile velocities a reactor temperature of the order of 4000°C would be required. Thermal output of the core would have to be about 100MW per ton of thrust developed for exhaust velocities of 32,000 fps or more. He stressed that the rockets would almost certainly need to be unshielded, and the degree of reliability to guarantee unpremeditated return to earth presents as big a problem as the development of the nuclear power plant itself.

Within the next ten years there was little likelihood of nuclear propulsion plant being built and operated by the UK for anything other than ships. Here, if the large submarine tanker was ever required it would probably only be made practicable by the use of nuclear energy. Real advantages might show at speeds of over 50 knots and at such speeds it was likely that propellers would be replaced by jet propulsion.

How to select the right alloy

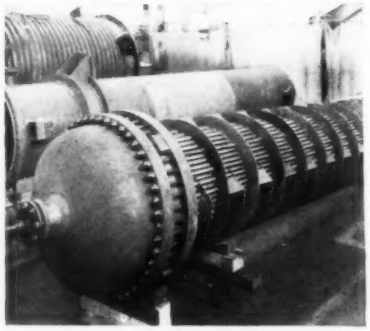
TO RESIST CORROSION

Many Wiggin wrought nickel alloys are outstanding because of their resistance to corrosion by a wide range of media.

Chlorination vessels of Monel used in the production of selective weed killers. Fisons Pest Control Limited.

Atmospheric Corrosion: INDOORS most high-nickel alloys are immune. In industrial sulphurous atmospheres Inconel is superior. OUTDOORS the rate of attack is low. Inconel remains bright in most atmospheres. Even where Monel tarnishes, there is no destructive corrosion.

Fresh and Salt Water: When water high in salts and dissolved gases is handled, Inconel is the preferred material. In salt water, Monel is generally preferred in submerged exposure and Inconel in exposure to marine atmospheres. Monel is the ideal material for propeller shafts, fastenings, valves and pump parts handling salt water.



Heat exchanger for chemical processing with tubes of Low-carbon A T Nickel welded to a nickel-clad steel tube plate. The dished head is also of nickel. Bertrams Limited.

Neutral and Alkaline Salts: Nickel resists this type of attack while Monel is widely used in salt processing. Inconel is especially suitable for equipment handling food and refrigerating brines since it resists pitting.

Acid Salts: Generally Monel is superior to nickel and Inconel with acid salts such as zinc chloride, ammonium sulphate and aluminium sulphate. Inconel is one of the few materials available for use in contact with hot, strong solutions of magnesium chloride and is superior for resisting oxidizing acid salts.

Oxidizing Alkaline Salts: Hypochlorites are the only common alkaline salts corrosive to Monel, nickel and Inconel.

Mineral Acids: Monel is among the few mechanically strong materials which resist corrosion by dilute hydrochloric and sulphuric acids. It is resistant to air-free hydrofluoric acids of all concentrations and at all temperatures including boiling. Monel is used in sulphonation, pickling and hydrofluoric acid alkylation. Nickel is useful in chlorination equipment.

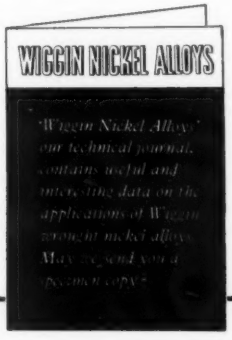
Oxidizing Acids: Such as nitric in concentrations over 20 per cent have little corrosive attack on Inconel.

Organic Acids and Compounds: Inconel resists this type of attack so well that it is widely used in food processing and pharmaceutical manufacture. Nickel is frequently chosen for food processing equipment because of its ability to protect purity. Monel is useful in resisting corrosion in the manufacture of fatty acids.

Alkalies: Alkalies such as caustic soda have practically no corrosive effect on nickel. In less severe applications Monel is often used. Inconel is chosen where alkaline sulphur compounds are handled.

Wet and Dry Gases: At atmospheric temperatures no dry gas is actively corrosive to nickel or to Inconel. Nickel is one of the most useful materials for handling chlorine, fluorine and bromine at temperatures up to about 540°C. and is free from corrosion by steam up to 425°C. Inconel is used for handling steam up to about 800°C. Above this temperature one or other of the Nimonic Series of Alloys is generally used.

The choice of materials for corrosion-resistance is a job for the expert. Beside Monel, Inconel and nickel, other alloys such as Corronel B and Ni-o-nel have been developed for specific problems. Our Technical Service engineers are always ready to give advice on the detailed applications of wrought high-nickel alloys in the light of many years specialised experience.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"Wiggin Nickel Alloys" our technical journal, contains useful and interesting data on the applications of Wiggin wrought nickel alloys. May we send you a personal copy?

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THE PHYSICAL SOCIETY

The Physical Society covers all aspects of physics in its conferences and publications. Below are given some items of particular interest to the nuclear physicist.

CONFERENCES ON NUCLEAR PHYSICS

Held twice yearly in various parts of the country.

PUBLICATIONS

Proceedings of the Physical Society—monthly. See especially issue of January 1957 B for papers on the Pinch Effect.

Reports on Progress in Physics—annually, containing articles on various aspects of physics. Separate articles are also available. Recent articles include :

Production and Measurement of High Temperatures
by W. Lochte-Holtgreven

Mesonic Atoms, by D. West

High Energy Protons
by A. E. Taylor

The Proton Synchrotron
by J. P. Blewett

Topics in Neutron Diffusion Theory
by J. H. Tait

EXHIBITIONS

An exhibition of Scientific Instruments and Apparatus is held annually in London. The next exhibition will be from 19th to 22nd January, 1959. The Handbook will be available in December. Previous Handbooks are still in print.

For full details of publications and membership apply to :

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Book Reviews

In print again

Sourcebook on Atomic Energy (2nd Edn) by Samuel Glasstone, Princeton 1958 : D. Van Nostrand. 641 pp Price 34s.

For far too long Dr Glasstone's monumental work has been quite unobtainable in this country—new or second-hand—and the appearance of a greatly improved second edition is an event to be welcomed by all nuclear scientists and engineers. Published as far back as 1950 the first edition of the *Sourcebook* went through about 50,000 copies in its English edition alone and with the tremendous growth in activity since that time it seems probable that the publishers will have a science best seller on their hands—particularly since the price is so moderate for such a wealth of material.

To those unfamiliar with the work it should be explained what the *Sourcebook* is: it is really a sort of *Materia Medica* of nuclear science—not a textbook. Nothing is fully developed, no proofs are given and irrelevant ephemeral details are omitted. But an outline at least is here to every basic concept as it is understood at present. Throughout, Dr Glasstone uses the historical approach and always acknowledges the authors of the various discoveries from Democritus down to the present day scientists. This means it can be read like a novel and in fact is quite hard to put down.

The value of Glasstone's *Sourcebook* is really twofold. It is extremely useful for brushing up one's half-forgotten physics and even filling gaps in knowledge: it is also invaluable as a starting point for beginning some new study. In the last respect it is a pity that even in the second edition there are no references given. Agreed, it would need a complete companion volume to list every original paper but one would have thought that a select bibliography at the end of each chapter might have improved the book.

The following are the main chapter headings: Foundations of atomic theory, fundamental particles, energy and radiation, atomic structure, natural radioactivity, measurement of nuclear radiations, properties of nuclear radiations, isotopes, acceleration of charged particles, artificial radioactivity, the neutron, nuclear forces and structure, fission, utilization of nuclear energy, reactors, the new elements, uses of isotopes and radiation, cosmic rays and strange particles, radiation protection and health physics. Altogether a work of great scholarship and one of remarkable value in these times.

W. Davidson

·00132d per word

Van Nostrand's Scientific Encyclopedia (3rd Edn) London 1958 : Van Nostrand 1846 pp Price £11

In the twenty years that separate the first edition of this monumental work from this complete revision the world of science has expanded at a terrifying speed and new ideas, concepts and even words are coming into current usage every day. The new Van Nostrand gallantly copes with this avalanche and is complete up to the end of 1957. On basic things such as mathematics it is particularly valuable and even on less finalized subjects like nuclear energy it concisely gives the situation at the time of writing.

The only possible way to review a book of this nature is to try a few spot checks: reading is out of the question as there are said to be 2 million words contained in its 14,000 articles and 100,000 definitions. This process failed to reveal any very startling omissions in fields familiar to the reviewer.

The encyclopedia of course covers the whole field of science and this accounts for its great bulk. A much more manageable system—which it is hoped the publishers will adopt for the inevitable 4th edition—would be to divide science into the two broad divisions of Life and Physical sciences. This will probably prove difficult when it comes to certain areas of organic chemistry but at least it would prevent *nephritis* getting mixed up with *neptune* and *neptunium*.

New editions seem to appear about every ten years and with the present rate of growth in all the sciences the 1968 edition looks like being a formidable undertaking but a very worth while one.

Meanwhile this edition should certainly be in any science or technical library worthy of the name.

Wheat and chaff

Separation and Purification of Materials by Rolt Hammond. London, 1958: Heywood & Co 337 pp £2 10s.

In trying to produce a technological textbook of interest to both the graduate and the non-graduate the author has certainly attempted something very much worth while, and the difficulty of achieving such an object satisfactorily can be

judged by the dearth of this type of book. It is therefore not surprising that the result does not quite succeed in reaching this high aim. Probably one of the main difficulties is that the book covers a very large field, which does not make it easy to deal with any one aspect sufficiently to present an adequate amount of data on the equipment available, factors affecting the choice of equipment and means of assessing the performance. To give a typical example of this one can take the chapter on size separation. This deals in some detail with screens manufactured by Russell Construction Ltd, but does not mention the very well-known Locker screen. A very useful inclusion would have been some data on various standard sieves, as misunderstandings on mesh size frequently lead to confusion in practice. Similarly under separation of solids from gases some information on cyclone sizes and pressure drops would have been invaluable but has unfortunately not been included. The author has probably also made his life rather difficult in the way he has subdivided his subject-matter, e.g. air separation appears under separation of solids, whilst sedimentation and fluidization appear under separation of solids from liquids; as far as their separating function is concerned all these depend on fluid drag and terminal falling velocity and they should be classified together. Finally there are important omissions in the book, such as the failure to mention the processes used for separation of gases by liquefaction.

L. Mitlin

This review originally appeared in CONTROL

Possibilities in atomic power

Chancen in der Atom-Wirtschaft by Heimo Hardung-Hardung. Düsseldorf 1958: Econ-Verlag GmbH.

From the viewpoint of the industrialist and economist, Herr Hardung-Hardung has written a useful review of the whole subject of atomic energy. On the whole, he avoids the more scientific aspects and concentrates on the technical, health and financial problems. An English book of this nature is badly wanted and *Chancen in der Atom-Wirtschaft* might well be a useful model although a direct translation would only be of limited interest in this country.

World nuclear activities

Actividades Nucleares en el Mundo by the Marquis de Loriana Madrid 1958 : Servicio de Estudios del Banco Urquijo

Published by the Urquijo Bank, a leading member of the Spanish Tecnatom nuclear energy consortium, this volume provides a brief semi-commercial review of nuclear activities throughout the world which should be particularly useful in Spanish speaking countries.

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HEAT EXCHANGERS

By W. HRYNIZAK, D.Sc., Dip. Ing.
C. A. Parsons & Co., Ltd.

This book is not concerned with the process of heat transfer itself, but with the apparatus performing this transfer and the best way of designing and fitting it into a gas turbine so as to obtain, depending on its applications an economical unit. It is felt that the manner in which the thermodynamical optimization of the gas turbine air preheater has been treated, will be of particular interest in connection with supercritical steam cycles and nuclear power applications.

The book will supply an authoritative and long felt need to the engineer and will not be without interest to the physicist who is more and more becoming involved in direct applications of thermodynamics. *Price 63s.*

GLOVE BOXES and SHIELDED CELLS

Editor: G. N. WALTON, M.A.
A.E.R.E. Harwell

In the United Kingdom Atomic Energy Authority, operating experience in handling bulk quantities of radioactive materials in the laboratory has been mainly obtained with α-active materials such as plutonium. Consequently in the choice of papers for the 1957 Harwell Symposium, of which this book is a record, most attention was given to the design and operation of equipment which has been developed for handling these materials. Experience gained in France, and in the U.S.A., as well as in the Research, Industrial, and Weapons Group of the U.K. was covered as fully as possible.

The increasing experience being obtained in handling irradiated fissile materials and high β and γ-active sources is reflected in the number of papers included here on the development and use of equipment for these sources which require shielding.

Many more people, in a large number of countries, will be using these techniques in the next few years and it is essential that a fund of information on safe methods be built up and made easily accessible to all. This publication from U.K.A.E.A., Harwell, will prove an invaluable guide for those engaged in meeting these needs. *Price 95s.*

Full details available, post free, from

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BOOK SERVICE

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NAMES IN THE NEWS

Managing director of Crossley-Premier Engines Ltd, **Mr W. G. Pinder** has joined the board of the parent company Crossley Brothers Ltd.

Mr Hugh Beck has been appointed to the Board of Crossley-Premier Engines —he is already on the board of Crossley Bros. **Mr J. I. Pugh,** previously secretary and chief accountant of Crossley Bros also joins the board of Crossley-Premier Engines and is succeeded at Crossley Bros by **Mr J. Shiels.**

Mr George Campbell has been made general manager of The Plessey Co's chemical and metallurgical division. He was formerly technical manager and deputy manager of the firm's Towcester plant.

Ashmore, Benson, Pease & Co, a member of The Power-Gas Group have appointed **Mr G. B. Taylor** to be sales manager (works division), and **Mr R. H. Foster** to be works manager.

Chris J. Brous has joined Atomics International as assistant chief of engineering. He was previously manager of AMF's nuclear laboratory and also worked at Argonne.

Dr R. V. Hughes has taken up a new research appointment at Ruston & Hornsby Ltd where he will be responsible for the administration of the research centre and the technical development programme for diesel engines.

Solartron Electronic Group have appointed **Mr T. Morrison** their instrument sales manager for the UK.

Mr K. F. Crayford has become sales manager of the government and industrial valve division of Mullard Ltd which comprises both the communications and industrial valve department and the government radio valve department.

President-elect of the Institution of Mining and Metallurgy for 1959-60 is **Dr J. H. Watson.** He succeeds **Mr J. B. Dennison.**

Dr Louis A. Turner has been appointed deputy director of Argonne National Laboratory. Dr Turner, who has written several articles on the subject of nuclear fission was formerly director of Argonne's physics division.

Mr W. E. Preston has joined the staff of Foxboro-Yoxall as technical representative in the north of England.

Joint managing director of Firth-Vickers Stainless Steels **Mr J. T. W. Dewar** has become managing director on the retirement of joint managing director **Mr C. E. Holmstrom.**

Sir Francis Evans and **Mr L. W. Cole** have been elected to the board of Dewrance & Co to fill the vacancies created by the resignation of **Admiral Sir Cecil Harcourt** and **Mr Hector McNeil.**

The British Oxygen Co Ltd have appointed **Mr A. P. M. Purdon** operations study manager. He will be in charge of central operational research and work study.

Sir F. EVANS

G. CAMPBELL

T. MORRISON

L. W. COLE

CATALOGUES AND BULLETINS

'About Vitreosil' is the title of a reference book just issued by The Thermal Syndicate Ltd, and it is believed to be the only book dealing specifically with fused quartz and silica in the world. A new material Spectrosil, claimed to be unaffected by exposure to gamma radiation and pile radiation is also mentioned.
Tick **No 185** on reply card

Revised edition of the Guide to correct instrument selection has been brought out by Taylor Controls Ltd, who also have new literature on a potentiometer transmitter and other instruments available.
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Geartight unions as used in many industries and supplied to both Berkeley and Hunterston are illustrated in booklet from Geartight Unions Ltd.
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Special issue of the Clyde Booth Newsletter commemorates the erection of their largest ever crane—the 200-ton capacity Goliath for Bradwell.
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Issued to coincide with the Geneva Atoms for Peace Exhibition, a booklet entitled TI's contribution to the nuclear engineering industry is available in six languages.
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Interesting brochure from Simon-Carves Ltd describes the many aspects of their work in the civil engineering field. Of particular interest is the work of their soil mechanics and site exploration division.
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Leaflet from Barlow-Whitney Ltd describes a recently introduced portable melting pot for zinc, lead, tin, etc. It is designed to operate at temperatures up to 600°C.
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Carrier system of absorption refrigeration which utilizes steam used industrially for heating or processing is concisely described in a publication from Carrier Engineering Co Ltd. Machine has push button and thermostatic controls.
Tick **No 192** on reply card

Sunvic Controls Ltd are able to supply technical publications on a wide variety of their products ranging from energy regulators to liquid level controllers. A brochure on instrumentation for atomic energy is also available; the text is in three languages.
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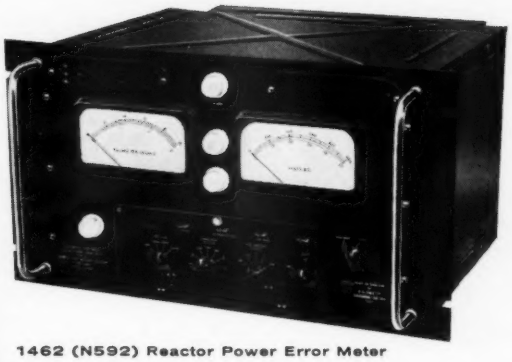
1389 (N588) Reactor Period Meter



1462 (N592) Reactor Power Error Meter

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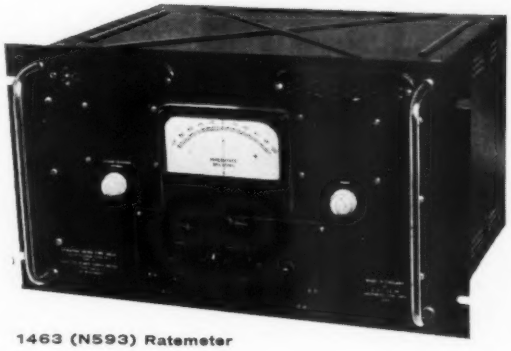

1463 (N593) Ratemeter

1463 (N593B) Fast Neutron Head

Ekco Electronics supplied and installed the complete nuclear instrumentation for reactors at Harwell, Dounrey and Sydney; the complete nuclear intrumentation for the new reactor at Risø, Denmark, will also be supplied by Ekco. In addition to these installations Ekco equipment has been incorporated in practically every reactor built to date. Typical instruments from the Ekco range of reactor equipment are illustrated. Please write for further information.

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Research Reports

The following reports have been made available to the public by the United Kingdom Atomic Energy Authority. They may be borrowed or photocopies obtained from the Science Library, London, Department of Industrial and Forensic Science, Belfast, the Mitchell Library, Glasgow, and the Central Libraries at Acton, Birmingham, Bristol, Kingston-upon-Hull, Leeds, Liverpool, Manchester, Newcastle-upon-Tyne and Sheffield. They are also deposited in the Copyright Libraries (i.e. British Museum; University Library, Cambridge; Radcliffe Science Library, Oxford; National Library of Scotland, Edinburgh; National Library of Wales, Aberystwyth) and in the Patent Office Library. Reports marked may be purchased from Her Majesty's Stationery Office.*

Reports are also available in the United States, from the USAEC depository libraries, a list of which will be found in NUCLEAR SCIENCE ABSTRACTS. Reports for sale may be purchased in the United States from: Sales Section, British Information Services, 30 Rockefeller Plaza, New York 20, N.Y.

AERE Harwell

The effect of holes in a reacting material on the passage of neutrons, with special reference to the critical dimensions of a reactor. *D. J. Behrens.* (Sept 1947. 11 pp) AERE T/R 103 2s 6d*

Helium-3 fast neutron spectrometer. Part 1. The proportional counter. *R. Batchelor, R. Aves.* (Oct 1954. 18 pp) AERE N/R 1499 3s*

Polarographic theory. Part 1. The influence of non-uniform mercury flow and intermittent polarization on the diffusion current. *G. C. Barker.* (Nov 1954. 13 pp) AERE C/R 1553 2s 6d*

The fine structure thermal neutron distribution in natural uranium-graphite lattices. *J. M. Lloyd, J. E. C. Mills.* (April 1956. 18 pp) AERE RP/R 1825 3s 6d*

Thermal diffusion plant for the enrichment of helium-3 from atmospheric helium. Part 2. Performance of the plant. *R. W. Bowring, R. H. Davies.* (March 1958. 40 pp) AERE GP/R 2058(2)

Measurements of the near-ground radon concentration on the AERE airfield. *H. J. Gale, L. H. J. Peaple.* (April 1958. 18 pp) AERE HP/R 2381

Instruments for the measurement of pressure and differential pressure of high temperature fluids. *S. T. Naish, T. R. Moss.* (April 1958. 13 pp) AERE R/R 2484

An FFAG synchrotron with straight sections having acceptable betatron oscillations. *R. Taylor, M. J. Mitchell.* (March 1958. 35 pp) AERE T/R 2495 5s 6d*

The effect of pile radiation on the reaction between hydrogen and graphite. *N. S. Corney, R. B. Thomas.* (June 1958. 31 pp) AERE C/R 2502

Some tests on standard electric motor insulation at high temperatures. *S. T. Naish, D. M. Harris.* (May 1958. 14 pp) AERE R/R 2525

The mechanical properties of uranium-molybdenum alloys. *M. B. Waldron, R. C. Burnett, S. F. Pugh.* (1958. 15 pp) AERE M/R 2554 5s*

Attenuation studies in the LIDO pool. *F. Avery, R. A. Dugdale.* (April 1958. 15 pp) AERE R/R 2558 2s 6d*

Organic and inorganic urinary excretion values in normal and irradiated subjects including observations on the preservation of the urine sample. *C. Sanders, P. C. Long, D. H. Pinnock.* (May 1958. 11 pp) AERE MED/R 2586

The alpha counting of a thick film with a pulse amplitude analyser type 1414A. *W. P. Hutchinson.* (May 1958. 10 pp) AERE MED/R 2587 1s 9d*

The diffusion of iodine in air. *H. J. de Nordwall, R. H. Flowers.* (May 1958. 12 pp) AERE C/M 342

DIDO remote active handling facility 'feel' unit. *K. J. Williams.* (June 1958. 15 pp) AERE ES/M 27 3s 6d*

A preliminary study of the production and properties of beryllium sheet. *N. A. Hill.* (April 1958. 17 pp) AERE M/M 193

Some experiments on the fused salt processing of liquid metal fuels. *J. K. Higgins.* (June 1958. 9 pp) AERE M/M 194

Notes on the toxicology of furfuryl alcohol. *F. M. Turner.* (May 1958. 4 pp) AERE MED/M 24

A variable area flowmeter using radioactive isotope techniques. *P. T. Blacker, D. M. Harris.* (June 1958. 8 pp) AERE R/M 159

The diffusion of magnetic fields in a cylindrical conductor. *J. H. Adlam, R. J. Tayler.* (April 1958. 22 pp) AERE T/M 160 3s 6d*

Stable configurations of a cylindrical gas discharge. *E. W. Laing.* (May 1958. 16 pp) AERE T/M 161 3s*

On the propagation of thermal waves in media with stored energy. *A. J. E. Foreman.* (May 1958. 12 pp) AERE T/M 162 1s 9d*

Industrial Group

Determination of the surface area of calcium fluoride by gas adsorption. *J. Brown.* (1958. 10 pp) IGR TN/C 888

OCTOBER DIARY

ICE Institution of Civil Engineers. IMechE Institution of Mechanical Engineers. IEE Institution of Electrical Engineers. IChemE Institution of Chemical Engineers. IP Institute of Physics. PS Physical Society. SCI Society of Chemical Industry. IM Institute of Metals. IMet Institution of Metallurgists. IMM Institution of Mining and Metallurgy. IPE Incorporated Plant Engineers. SIT Society of Instrument Technology. BritIRE British Institution of Radio Engineers. RSH Royal Society of Health. IR Institute of Refrigeration.

THURSDAY 2

GRANGEMOUTH SIT Data loggers *H. Williamson* 7.00 at the Leapark Hotel

MANCHESTER IMechE Paper on ZETA 6.45 at Engineers' Club, Albert Square

GLASGOW IMechE Application of nuclear power to marine propulsion *J. E. Richards* 7.30 Royal College of Science and Technology

FRIDAY 3

KILMARNOCK IMechE Repeat of above paper 7.30 at the Dick Institute

CHELTENHAM BritIRE Nuclear instrumentation *J. Thomas* 7.00 at North Gloucestershire Technical College

WEDNESDAY 8

BLACKBURN IMechE Lecture on atomic energy 7.00 at North Western Electricity Board's offices, Jubilee Street

THURSDAY 9

LEICESTER IProdE Development of high-speed machining techniques for non-ferrous materials *S. Radcliffe* 7.15 at Wadkin Ltd, Green Lane Works

WEDNESDAY 15

NEWCASTLE SIT The progress of temperature measurement in industry *R. Postle* 7.00 at King's College, Stephenson Buildings

THURSDAY 16

LEICESTER SIT Semi-conductors and their applications *G. M. Ettinger* 7.00 College of Technology and Commerce, The Newarke

MONDAY 27

LEEDS IPE Atomic energy *R. F. Jackson* 7.30 Fuel Department Lecture theatre, New Building, Leeds University

TUESDAY 28

LIVERPOOL IMechE Application of nuclear power to marine propulsion *J. E. Richards* 6.30 at Liverpool Engineering Society's Rooms, 24 Dale Street

FRIDAY 31

GLASGOW SIT Control and instrumentation of a nuclear reactor *A. B. Gillespie* 7.15 at Scottish Building Centre, 425 Sauchiehall Street

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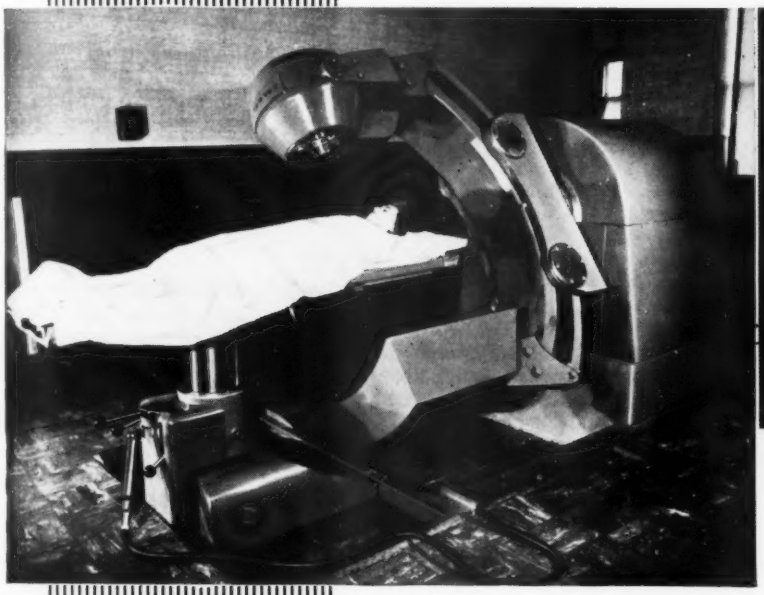

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An orbital teletherapy unit using G.E.C. Heavy Alloy.
With acknowledgements to Atomic Energy of Canada Ltd.

A 6″ G.E.C. Heavy Alloy Sphere weighing 65 lbs. being placed in an 8″ lead wall in the Isotope Division, Harwell.

Informative publication No. 3861 on application.

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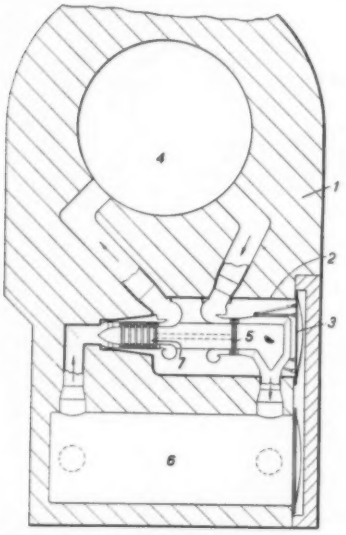
NEW IDEAS
nucleonic patents

Self-driving gas circuit

Considerable saving in pumping power in the gas circulation circuit is achieved by this suggestion of directly linking a gas turbine to the compressor and incorporating it in the coolant circuit. In fact, in principle the whole of the heat output is passed on to the secondary heat exchanger, but in fact there will be a small temperature drop across the turbine. It is particularly applicable to gas-cooled, solid homogeneous or gaseous-fuelled reactors. In the design described, primary coolant is helium pressurized to



799,212 ALMOST PERPETUAL MOTION

1 Shield
2 Pressure vessel
3 Sealing plate
4 Reactor
5 Two-stage, axial-flow gas turbine
6 Heat exchanger
7 Twelve-stage, axial-flow gas compressor

10 atm, inlet and outlet temperatures are 350 and 750°C and the heat output is approximately 30 MW. Turbine inlet and outlet pressures are 142·4 and 117·8 psi and the compressor has a compression ratio of 1·2771 with an inlet pressure of 115·5 psi.

799,212 Improvements in or relating to nuclear reactors *United Kingdom Atomic Energy Authority* (inventors: P. Fortescue and J. P. Middleton) Appn: Dec 3, 1955 Pubd: Aug 6, 1958

Variable reactor load

Using a cascaded bank of heat exchangers operating at high, medium and low pressures a variable load can be supplied from a reactor plant. The coolant passes through them from high to low pressure and if the demanded load falls below the reactor output, steam is discharged through the boilers progressively and finally from the l.p. side to the condenser. If the required load exceeds output, steam from an auxiliary furnace is brought into the turbine. The temperature of the coolant may be controlled either by bypassing feed water past the low pressure economizer or varying the pressure in the low pressure boiler.

797,725 Improvements relating to power plant including a nuclear reactor. *Metropolitan-Vickers Electrical Co Ltd* (inventor: W. Eccles) Appn: Feb 9, 1954 Pubd: July 9, 1958

BWR gives superheated steam

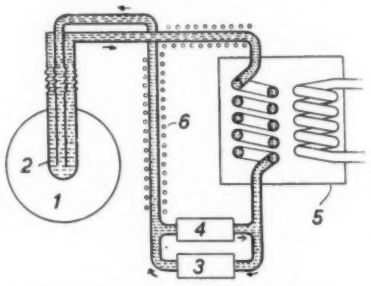
This is another form of Babcock & Wilcox's idea for producing superheated steam with a breeder reactor by passing the steam produced in the core through the blanket of fertile material. In their no 799,725 (NP June 1958, p 298) the reactor is a solution-type; here it is a BWR using either light or heavy water, fuelled with solid rod-type elements. The blanket—U-238 or thorium rods—surrounding the core is contained in the same pressure vessel. Cooling water flows upwards through the core, emerging as a steam-water mixture. After separation in a ring of whirl chamber steam separators, the steam passes down through the blanket where it is superheated and out of the pressure vessel to the point of use. Both fissionable and fertile elements are constructed so that they can be interchangeable to achieve maximum burnup and to maintain constant ratio of core to blanket heat output. By shifting each element at loading a rough control of the superheat in the steam is possible.

799,725 Nuclear reactor and method of operating same *Babcock & Wilcox (USA)* Appn: Nov 30, 1955 Pubd: Aug 13, 1958

Fast reactor control

At high neutron energies the cross-sections of most substances become very low so that control of fast reactors by a neutron absorber is not generally satisfactory and it is usually achieved by removal of part of the fuel. However Metrovick here suggest the use of liquid lithium which is a good moderator and an efficient absorber of thermal neutrons. (It also has a resonance peak at 2 to 3 MeV.) With a melting point of 186°C it would be liquid at the high temperatures anticipated in fast reactors. It is contained in a closed circuit, the control rod itself consisting of two concentric flow and return pipes. Either the effective volume or the position of the liquid may be varied to give the required control—in the form illustrated, the 'rod' is attached to the fixed pipes by expandable tubing. The liquid circulates through a heat exchanger, a small by-pass permits continuous removal of by-products and any necessary replacement of lithium, and heating coils are provided to keep the lithium liquid during shut-down.

799,001 Improvements relating to nuclear reactors *Metropolitan-Vickers Electrical Co Ltd* (inventor: A. W. Aiken) Appn: Feb 17, 1956 Pubd: July 30, 1958



799,001 LIQUID LITHIUM CONTROL ROD

1 Core
2 Control rod
3 Pump
4 By-pass
5 Heat exchanger
6 Heating coils

In brief

An unusual specification is 795,596 on **fusion,** taken out in Belgium by a Russian, Theodore Volochine, living in France. He claims to have achieved greater probability of fusion between nucleons and between nucleons and nuclei by applying polarizing magnetic fields to the reagent parts in such a way that the relation of their magnetic moments helps towards fusion. He also suggests a simple apparatus for achieving this.

A process for the preparation of carbonaceous material suitable for **moderator or reflector** is described in two patents by the Dutch firm N.V. de Bataafsche Petroleum Maatschappij. 798,030 describes the preparation of deuterated polycyclic hydrocarbons by the so-called 'trickle technique' employing catalytic exchange. The carbonization of this is then dealt with in 798,029.

A **control system** using variation of moderator level only is described in 792,972 by Atomic Energy of Canada. Applied for in 1956, it is probably the system used in the new NPD-II design.

Applied for ten years ago, 799,771 describes a method of **canning uranium** in compacted metal powder—preferably beryllium, zirconium or a beryllium-aluminium mixture—both powder and fuel being at a temperature above the beta-gamma transition point of uranium.

These abstracts are made from British Patent Specifications with the permission of the Controller of Her Majesty's Stationery Office. Complete specifications can be obtained from the Patent Office (Sales Branch), 25 Southampton Street, London, W.C.2. 3/6 a copy (including postage, inland and abroad)

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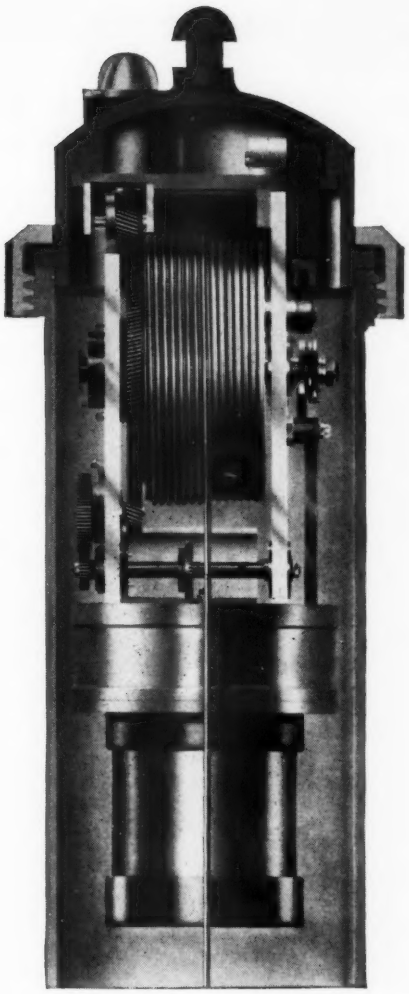

A complete reactor control head mechanism designed by Sperry, with a number of special features to ensure safety, reliability and ease of operation and maintenance.

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Length of case, inches	2	1-1/2	1-63/64	2-13/16	1-9/64	25/32	19/32	1
Shaft diameter, inches (nominal)	1/4	1/8	1/4	1/4	1/4	1/8	1/4	1/4
Coil length, inches (approx.)	46	18	45	140	14	1·9	3·1	8·2
Mechanical rotation	+4° 3,600°—0°	+10° 3,600°—0°	+1° 3,600°—0°	+4° 5,400°—0°	+4° 1,080°—0°	360° cont.	360° cont.	360° cont.
Electrical rotation	+4° 3,600°—0°	+10° 3,600°—0°	+1° 3,600°—0°	+4° 5,400°—0°	+4° 1,080°—0°	354°±2°	352°±2°	358°±1°
Resistance range, ohms	25 to 450K	25 to 100K	50 to 400K	40 to 1 meg	5 to 130K	1K to 100K	25 to 49K	50 to 163K
Best pract. resist. tol. (*a*)	±1%	±2·5%	±1%	±1%	±1%	±2%	±1%	±1%
Best pract. linearity tol. (*b*)	±0·05% 1K & up	±0·05% 10K to 50K	±0·025% 5K & up	±0·01% 10K & up	±0·1% 5K & up	±0·2%	±0·25% 2K & up	±0·1% 5K & up
Max. noise millivolts (*c*)	250 2K & up	250 1K & up	100	250 5K & up	250 500 & up	100	100	100
Watts, at 25°C ambient (*d*)	6·9	2·8	6·9	13·8	4·1	1·5	2·8	6·9
Watts, at 40°C ambient	5	2	5	10	3	1·2	2	5
Weight, oz. (approx.)	4·4	1	4·5	13	2·5	0·6	2	5·9
Max. starting torque, oz. in.	2	0·7	1·3	2·7	1·8	0·05	0·7	1·3
Max. running torque, oz. in.	1·5	0·6	0·9	2	1·3	0·05	0·5	0·5
Moment of inertia, gm. cm.²	18	0·3	22	200	7	0·12	2·8	8·6
Max. taps	28	32	28	80(*e*)	24	9	9	33
Min. distance between taps	20°±1°	45°±2°	20°±1/2°	15°±1°	20°±1°	30°±1°	30°±1°	10°±1°
Max. ganged sections	3	consult factory	2	3	3	5	no ganging	8
Life expectancy, shaft revs.	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000

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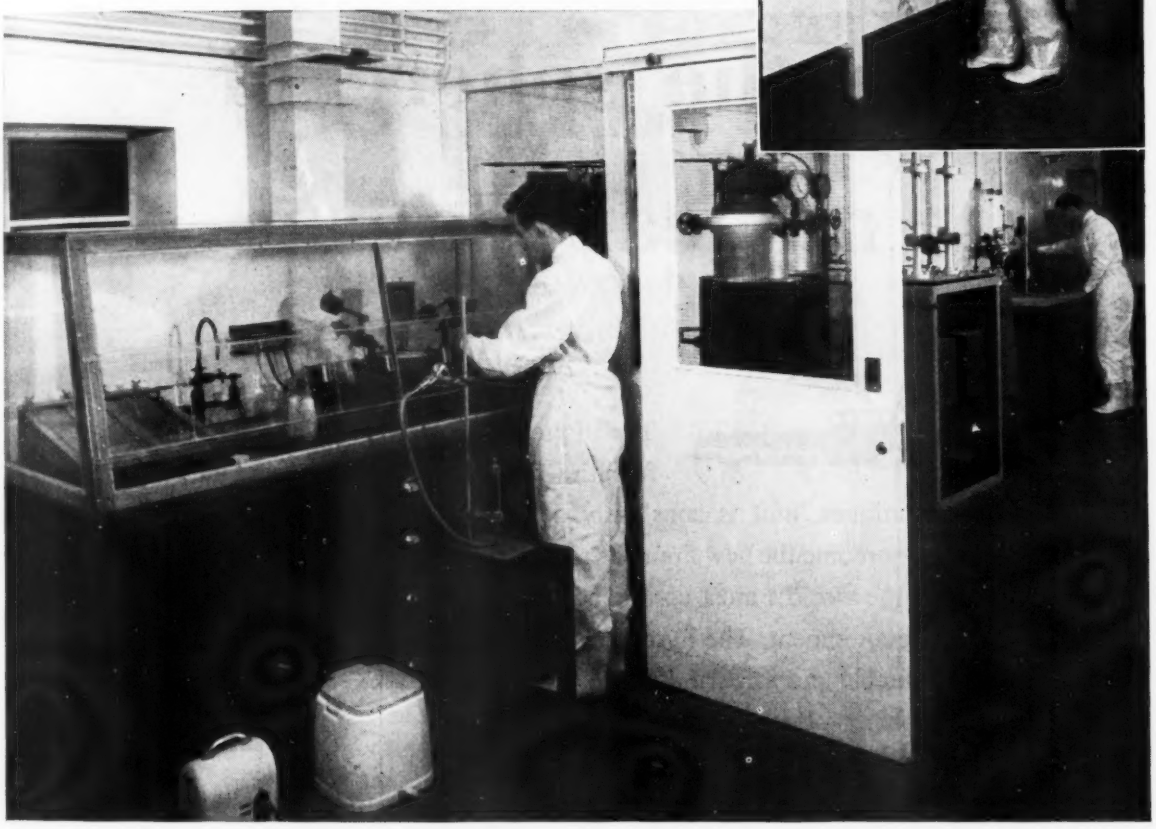
G.E.C. Nuclear Research and Development

BERYLLIUM



The thermal efficiency of a gas-cooled nuclear power station is largely dependent on the maximum temperature attained by the coolant gas. This temperature is limited by the properties of the various constructional materials. The metals at present in general use for the fuel-can, magnesium alloys, are restricted to around 450° C.

Current information suggests that a beryllium fuel-can might be operated at about 600° C. This would permit outlet gas temperatures to be raised by at least 100° C. above present levels.

Beryllium has a very low neutron-absorption cross-section; its resistance to oxidation is good in both wet and dry carbon dioxide; its melting point (1280° C) is much higher than that of other metals currently used for fuel-cans and its high-temperature strength is excellent. A great deal of work must be done, however, to define the limiting conditions under which a beryllium-canned fuel element could be used. This work is complicated by the fact that beryllium is a toxic metal, and it is therefore necessary to adopt the most stringent precautions in all operations involving its use.

There is a new laboratory at the Erith headquarters of the G.E.C. Atomic Energy Division entirely devoted to research on the metallurgy and technology of beryllium metal. Its construction, layout, equipment and, above all, its elaborate ventilation system have been carefully planned so that these important investigations can be carried out in complete safety.

The work of this new laboratory is but a small part of the research and development directed by the G.E.C. towards the attainment of even cheaper power from nuclear sources.

G.E.C. *Atomic Energy Division*

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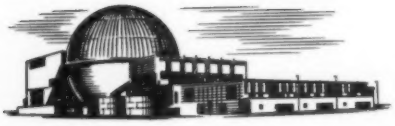

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* **Gas Activity Monitoring Equipment—a patented system developed by Sunvic Controls, which is being supplied for C.E.G.B. use at Berkeley nuclear power station. For further information, please contact:**

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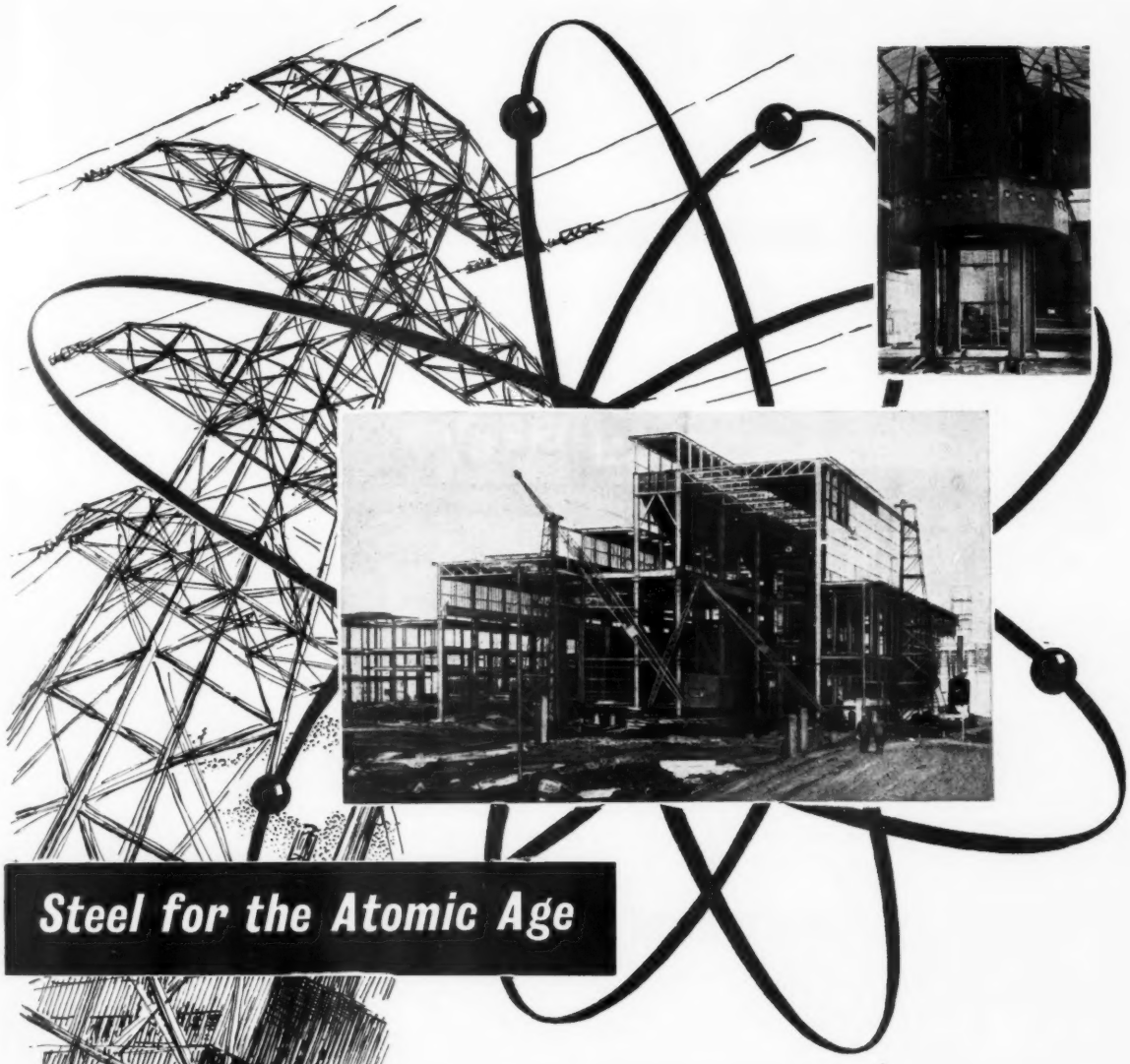
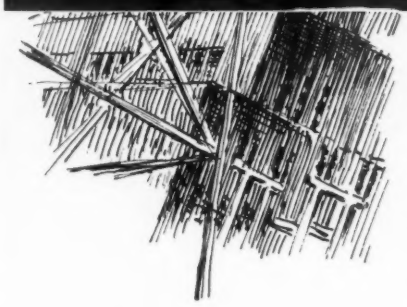


Steel for the Atomic Age



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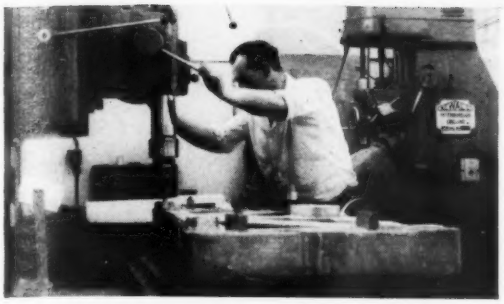

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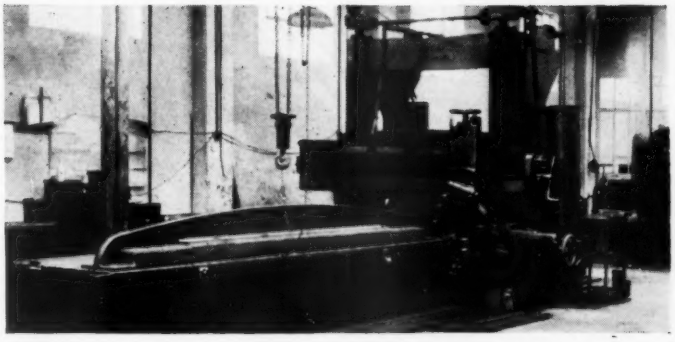

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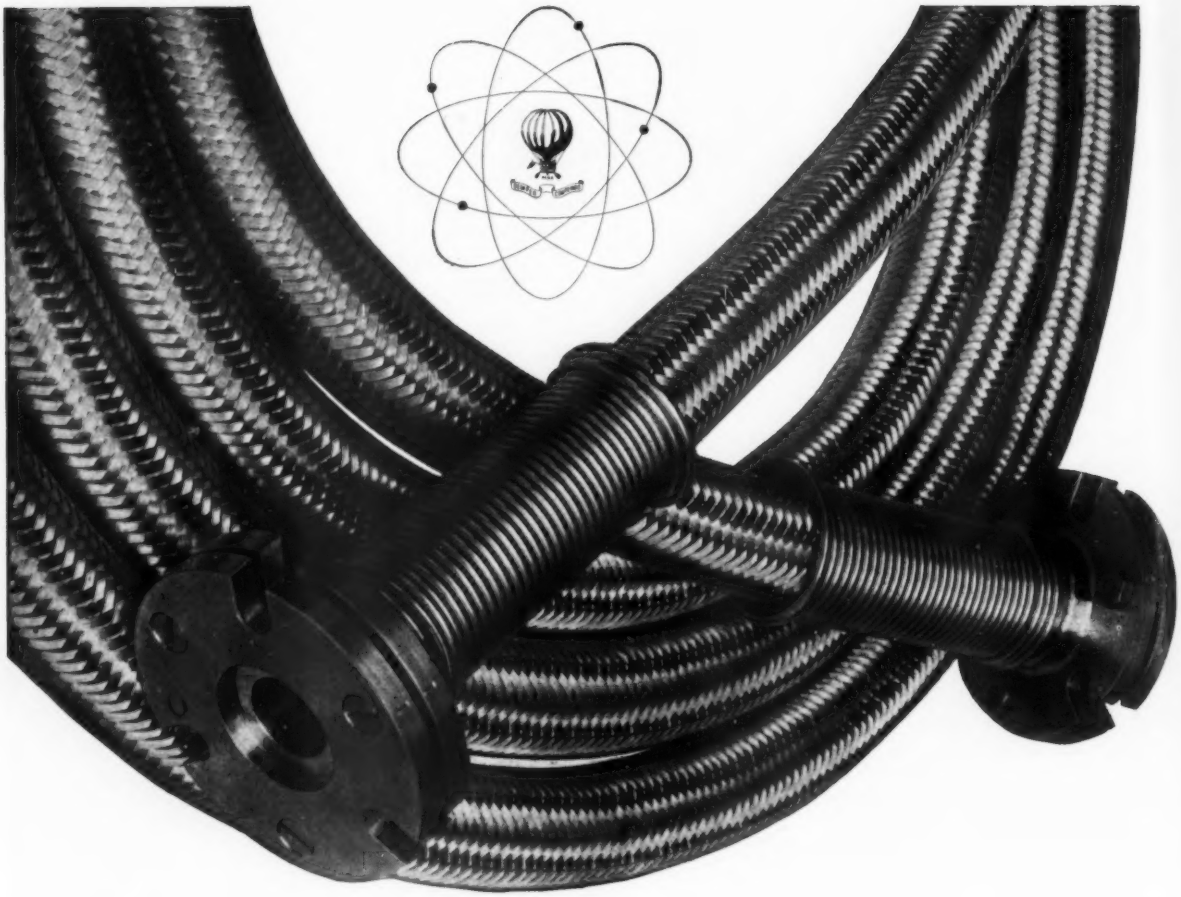

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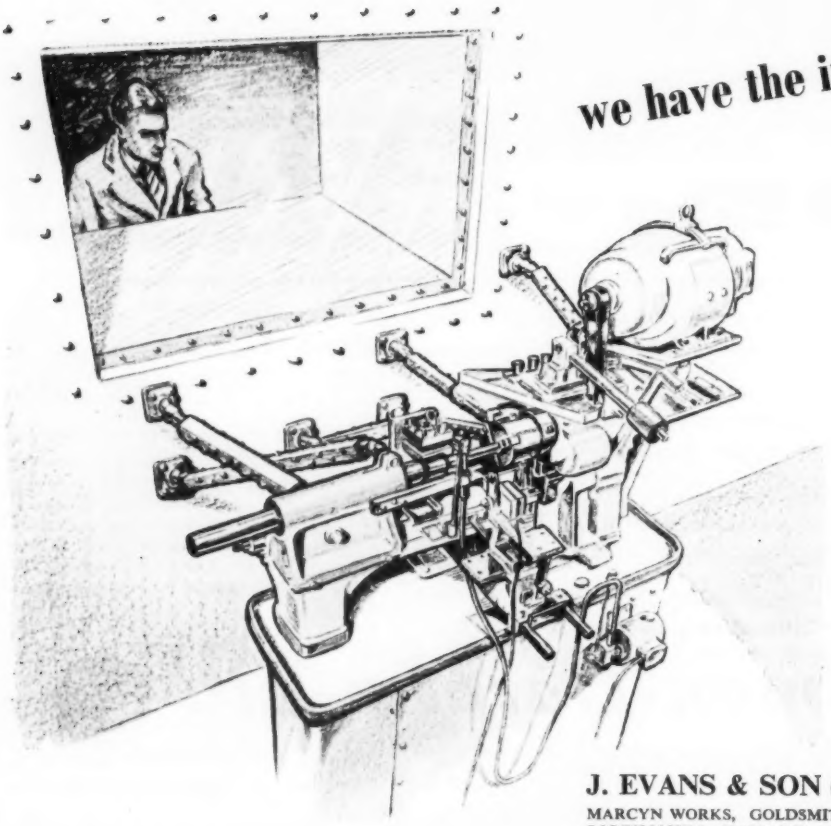

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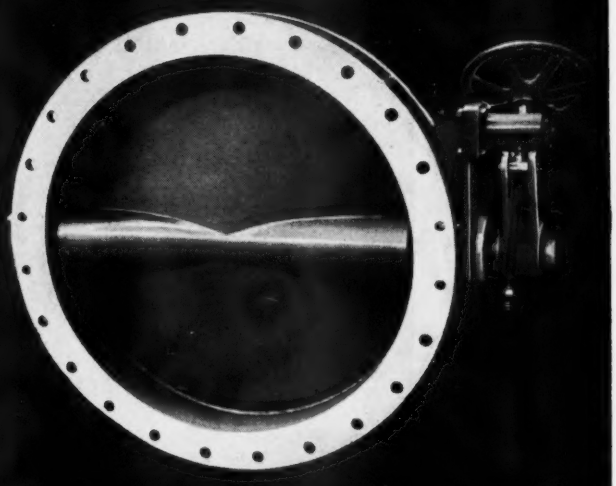

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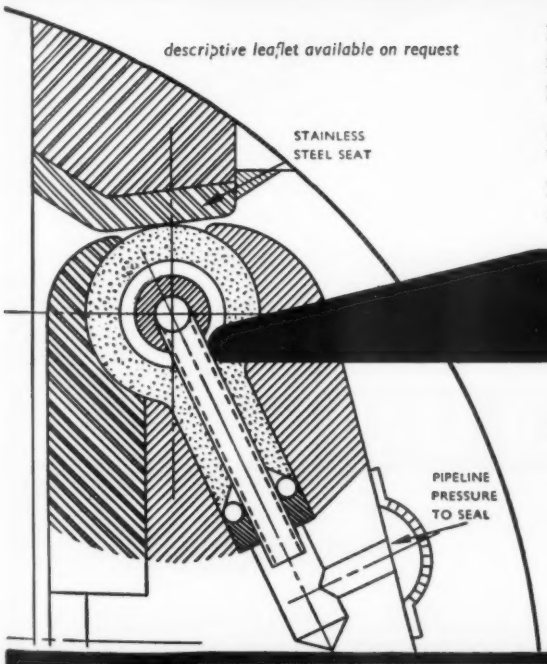

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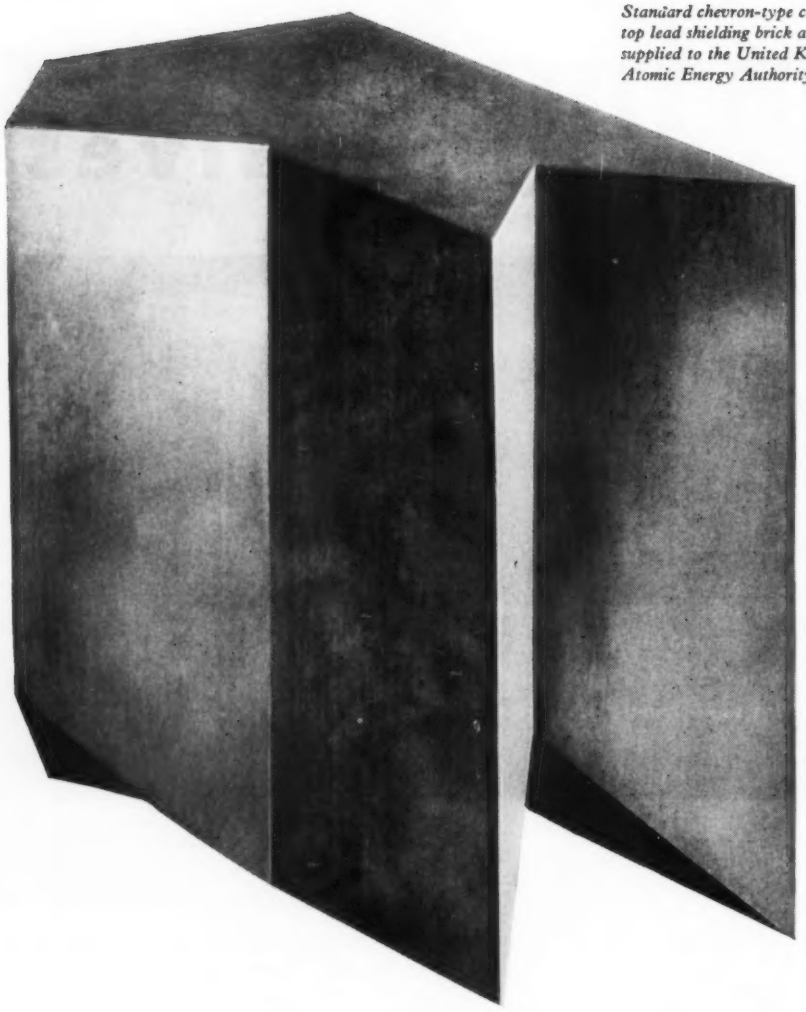

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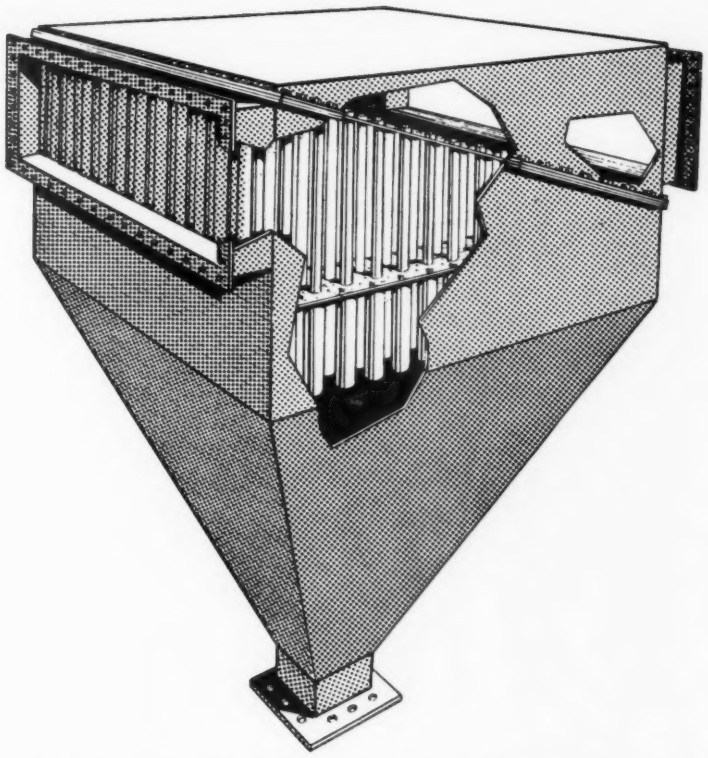

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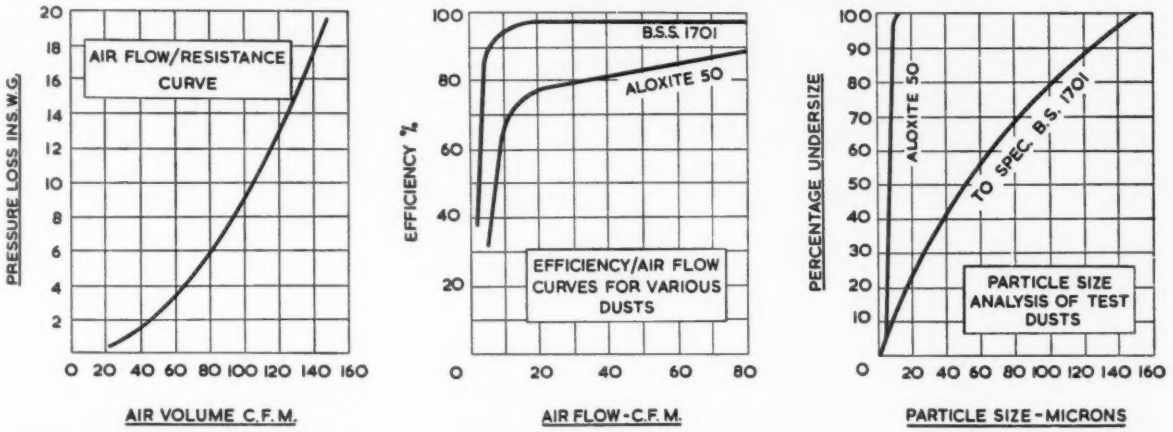

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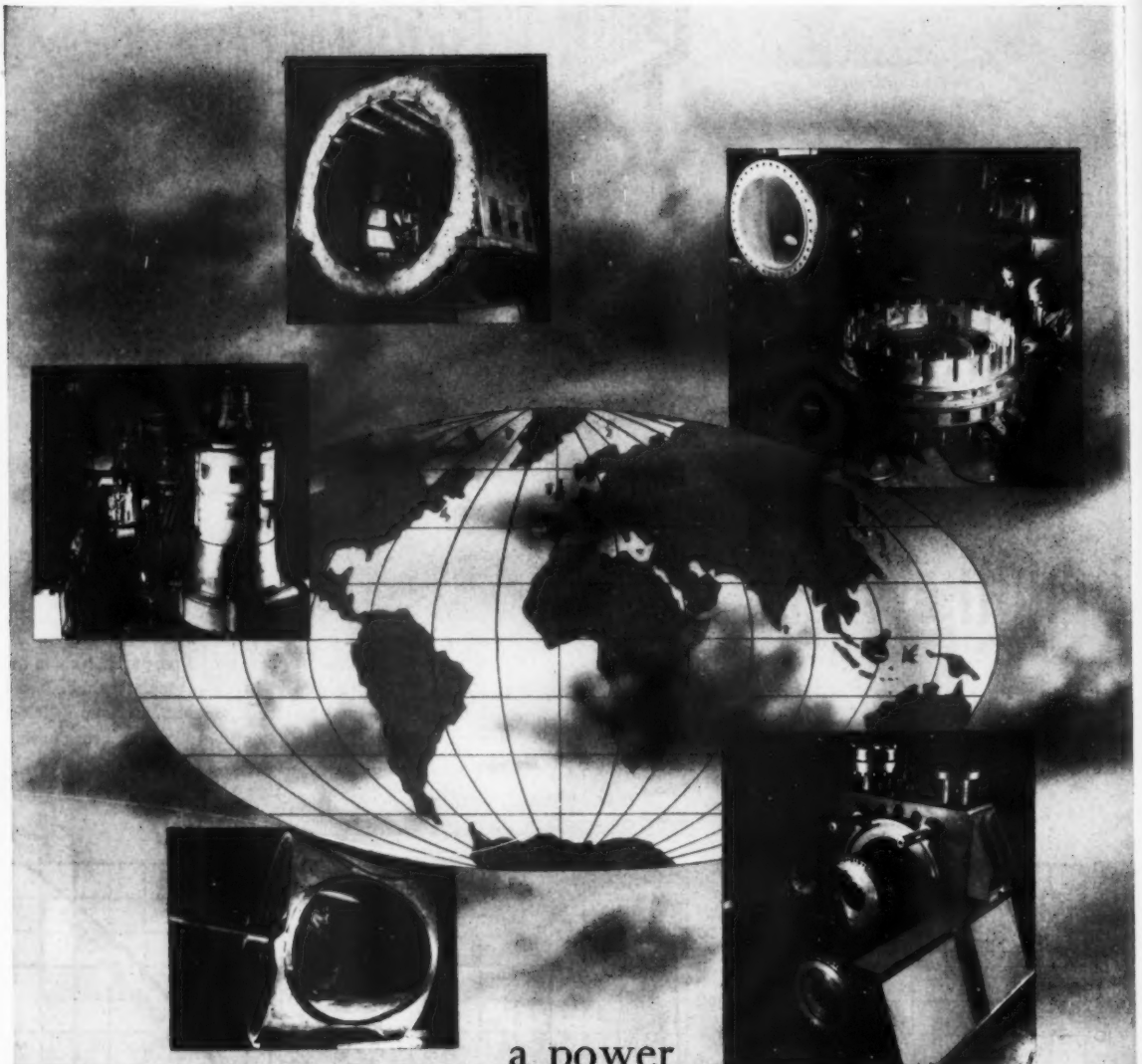

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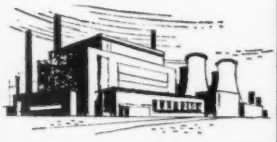

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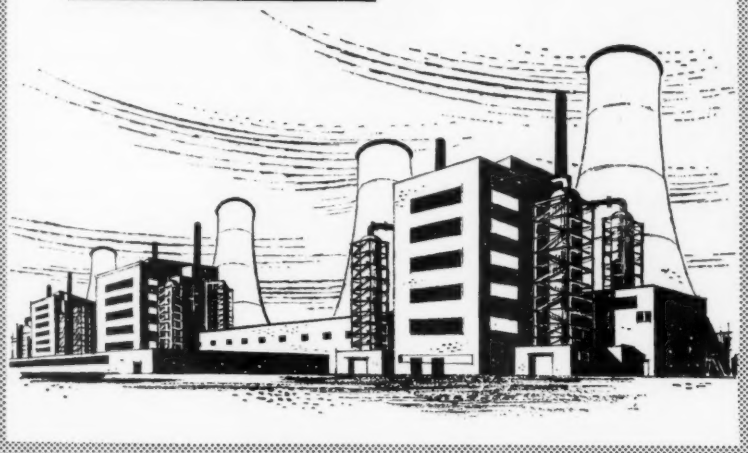

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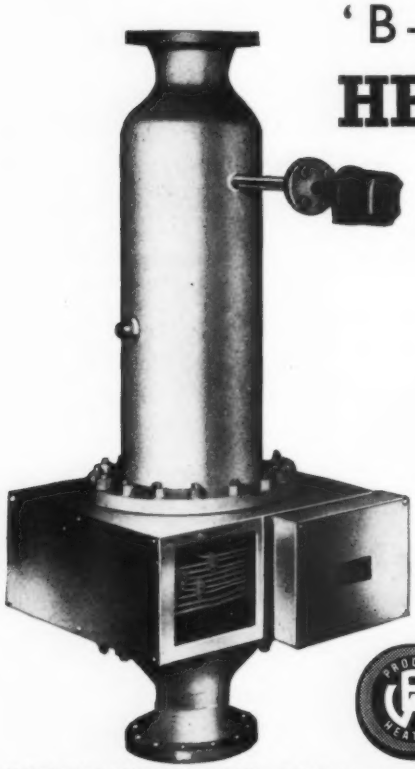

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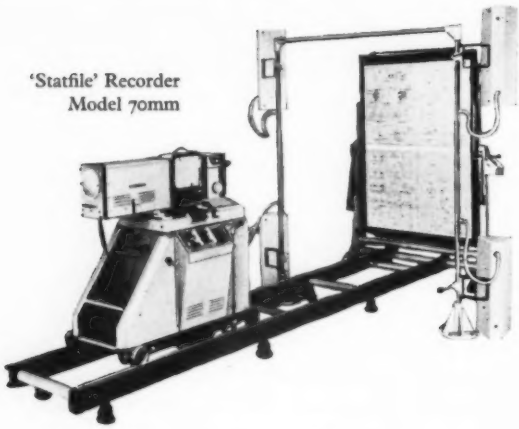

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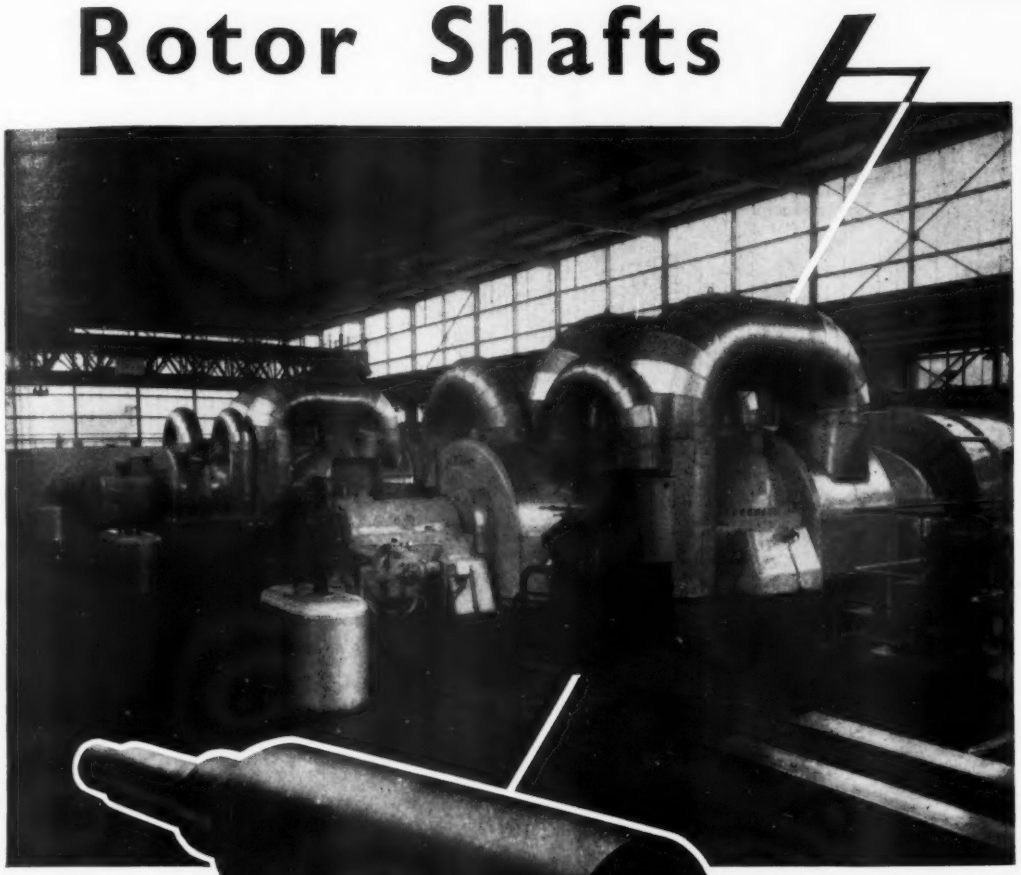

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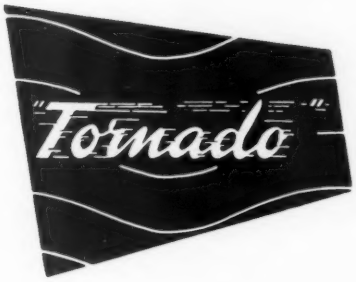

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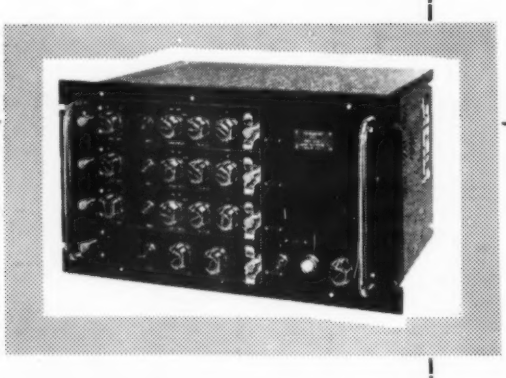

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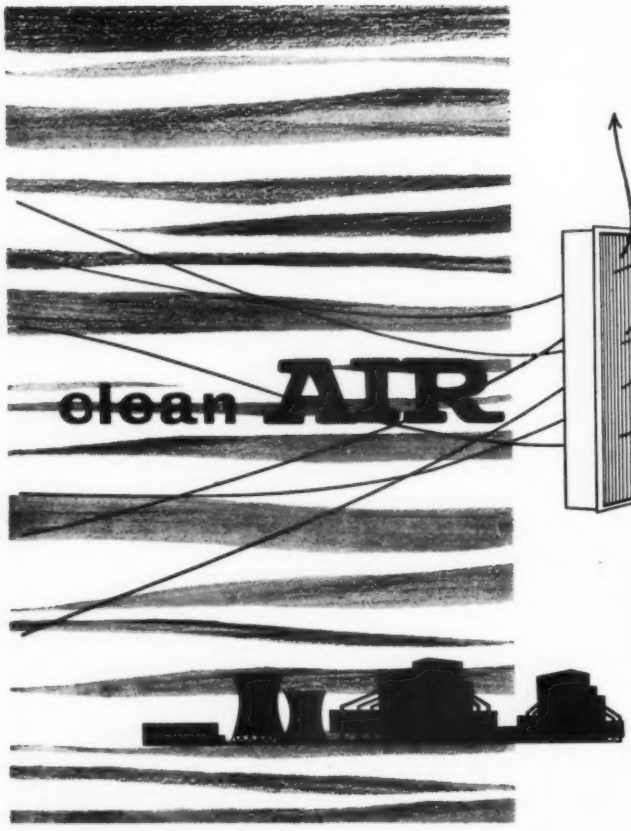

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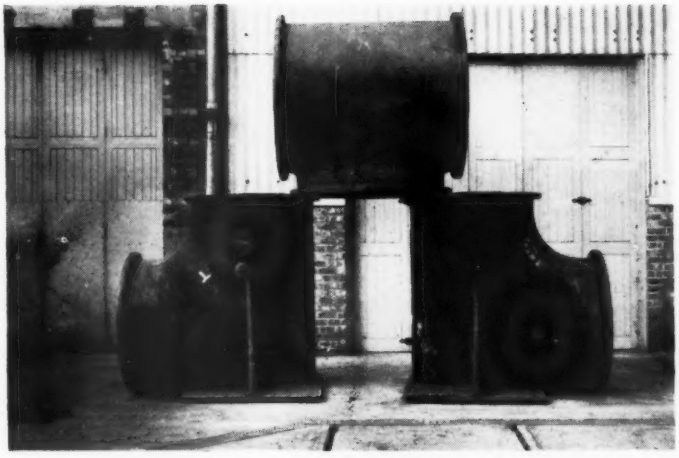

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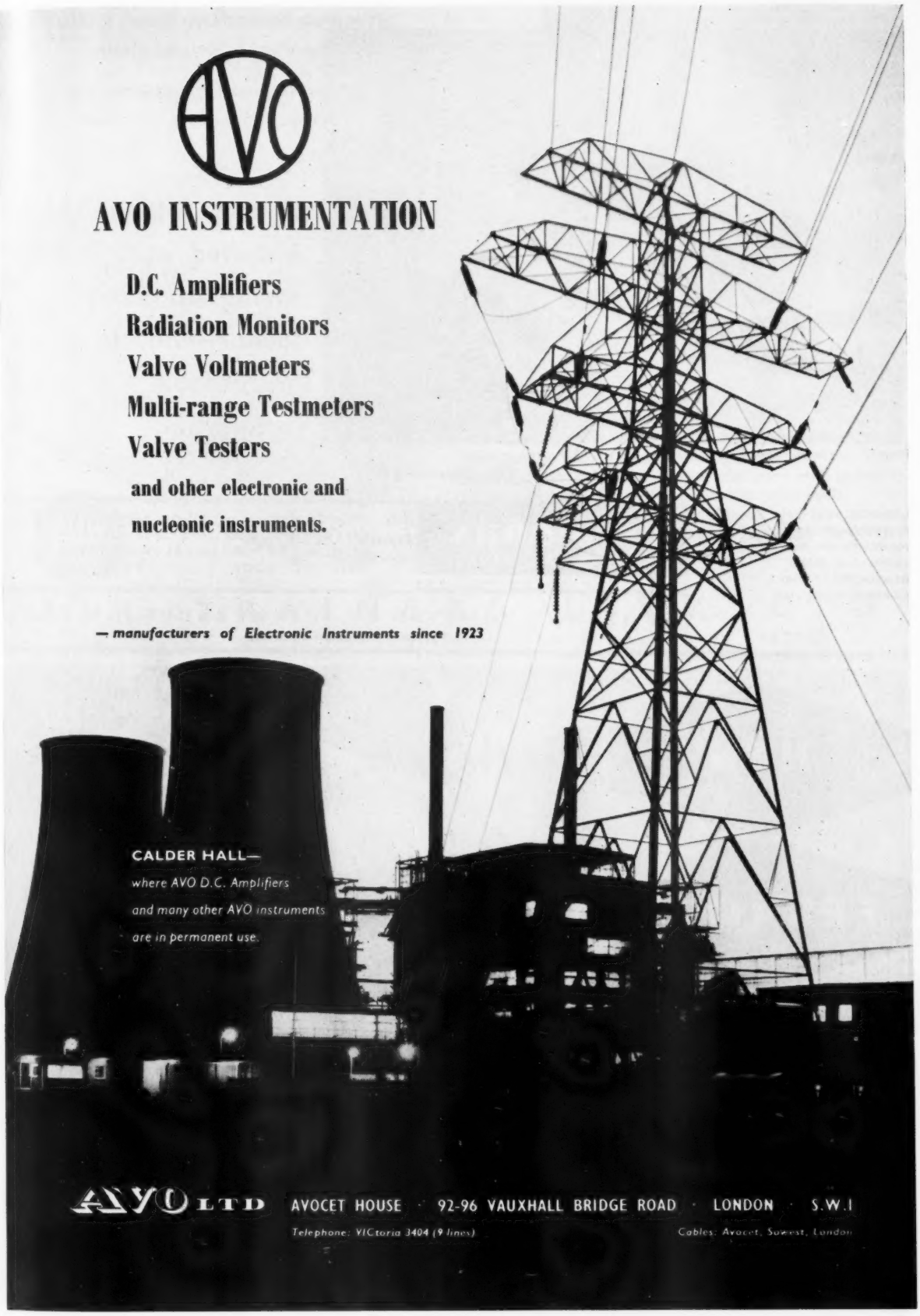

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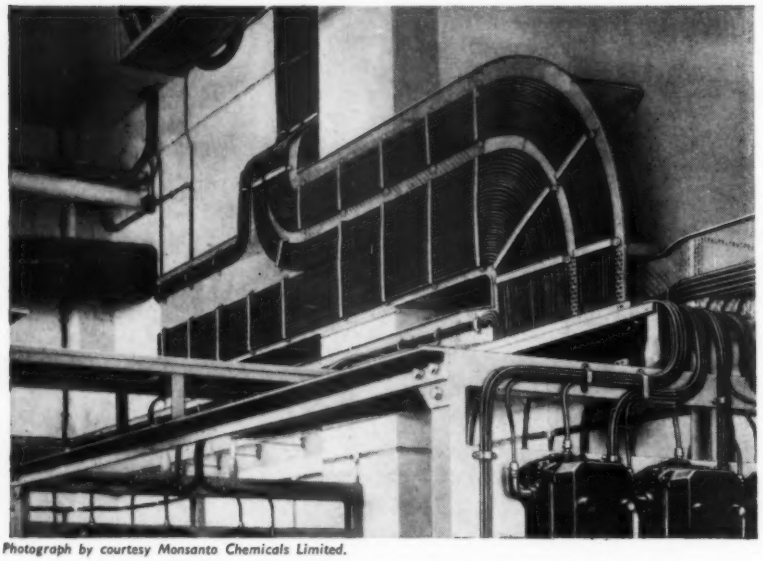

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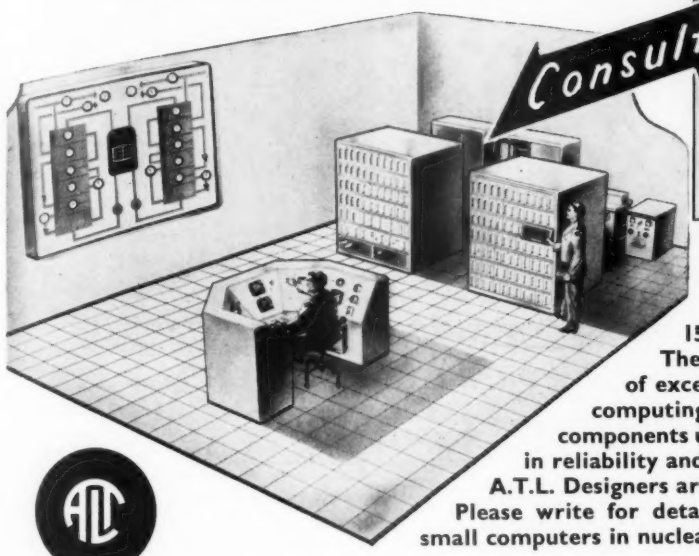

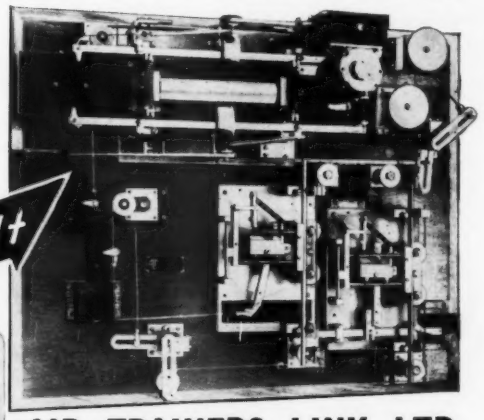

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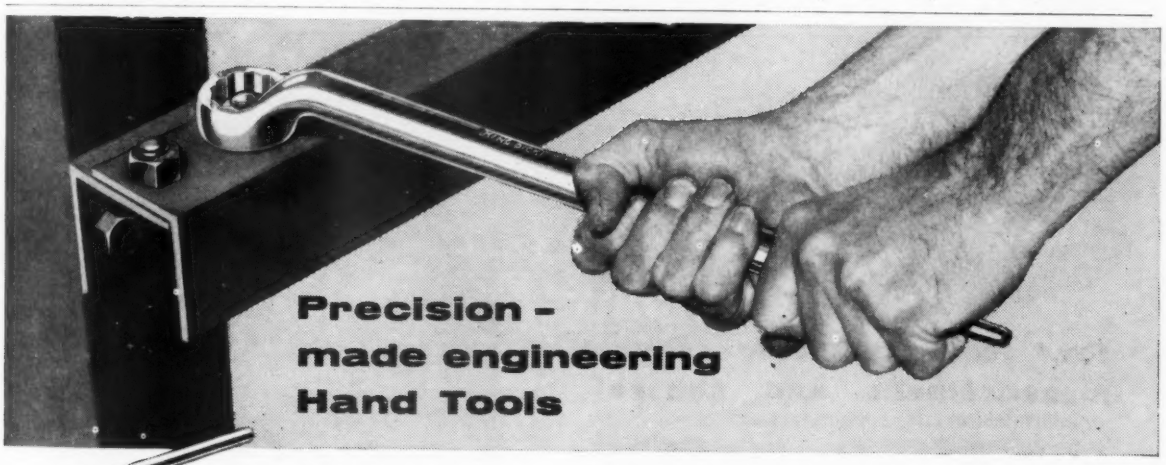

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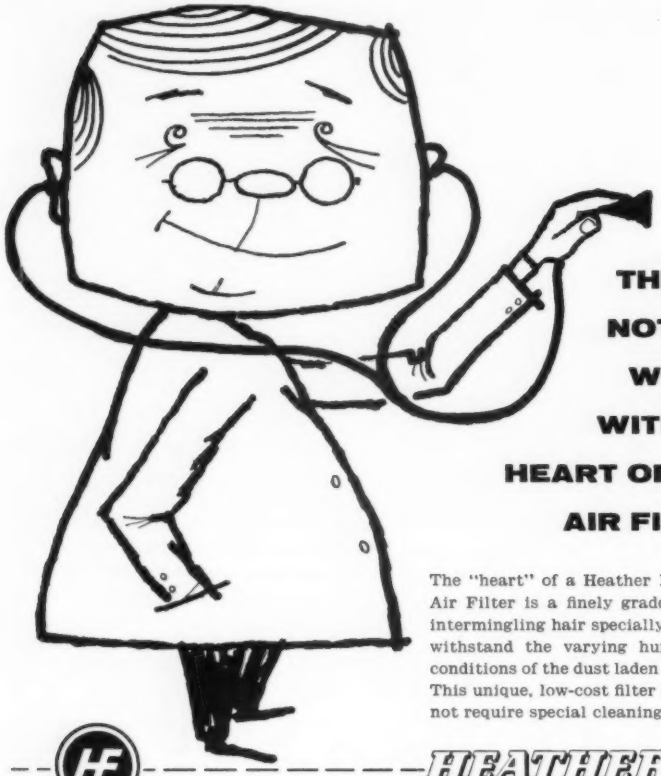
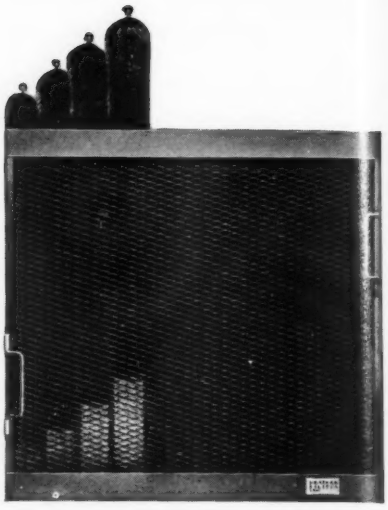


THERE'S NOTHING WRONG WITH THE HEART OF THIS AIR FILTER!



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This unique, low-cost filter system does not require special cleaning equipment, fluids, replacement pads or fabrics — simply remove the filter brushes and free them from dust by shaking or suction cleaning. Heather Multi-Brush Air Filters may be built-up into units to provide the area necessary for any given air flow.

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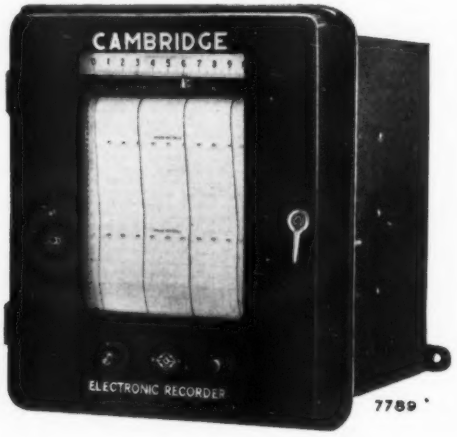

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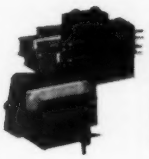

Multiple contact relay type SMF Contacts up to 3 pole DT Rating 2A 250v AC

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This rack of relays shown left occupies a length of only 9 inches.

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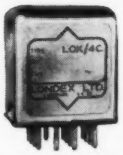

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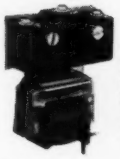

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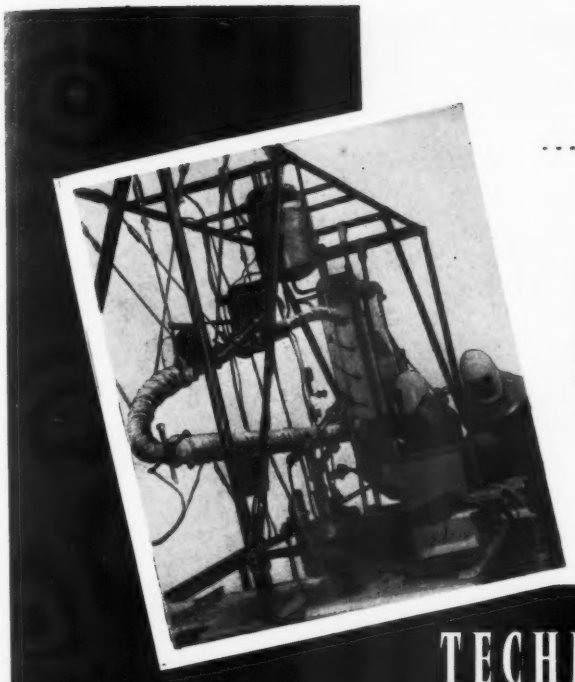

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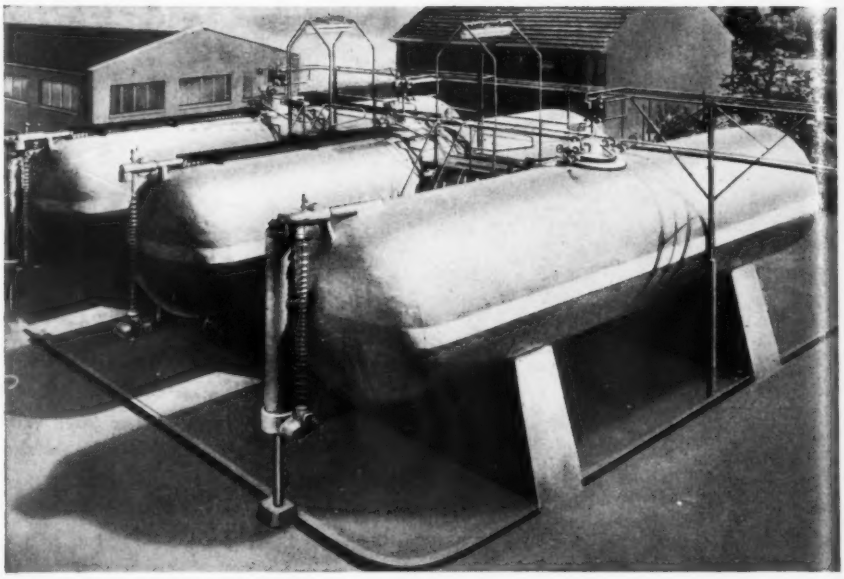
CO_2



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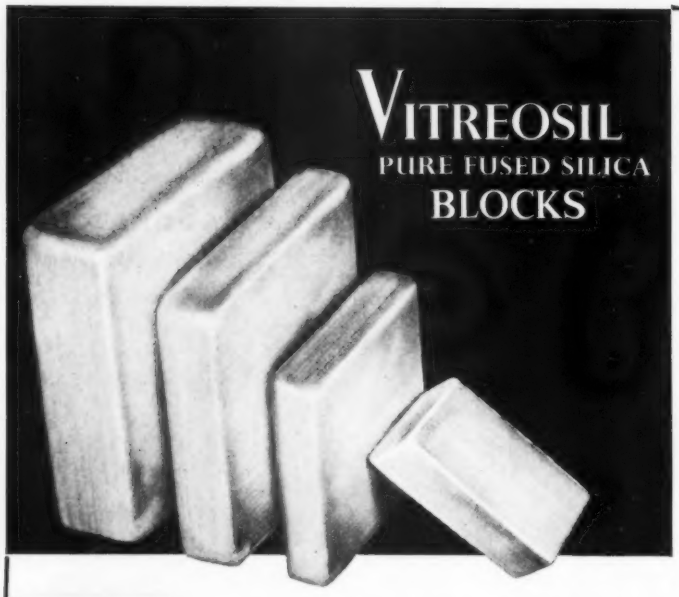

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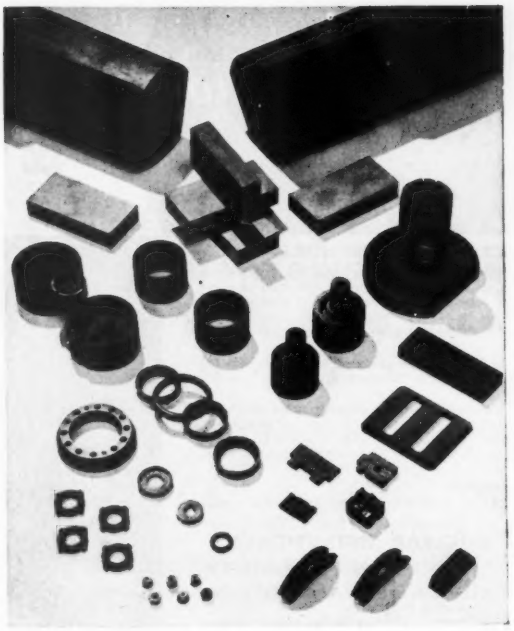

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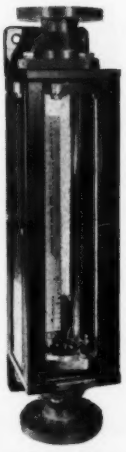

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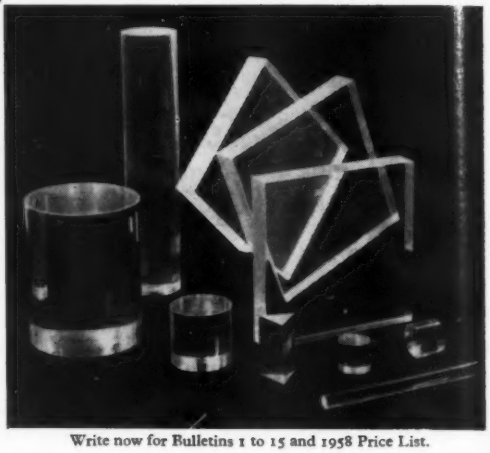

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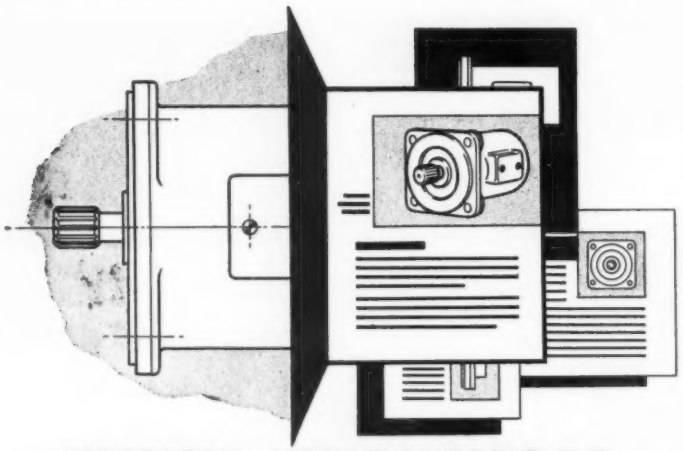

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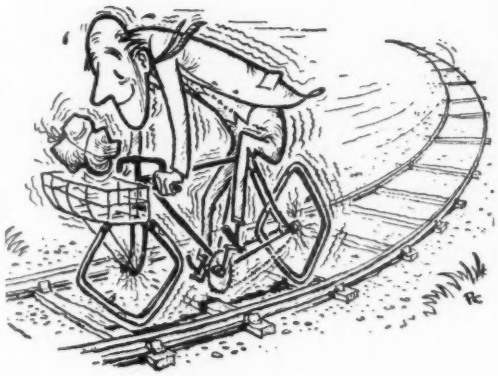

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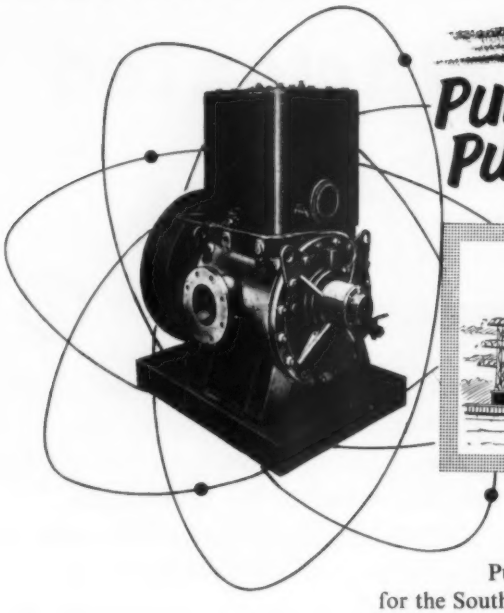

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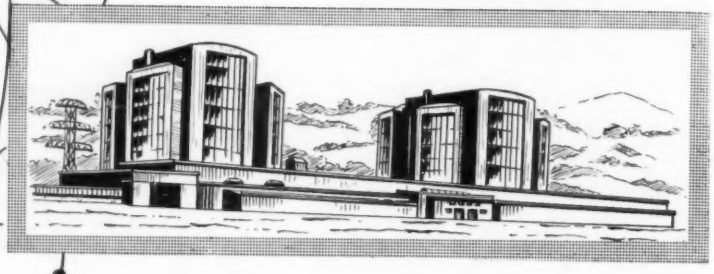

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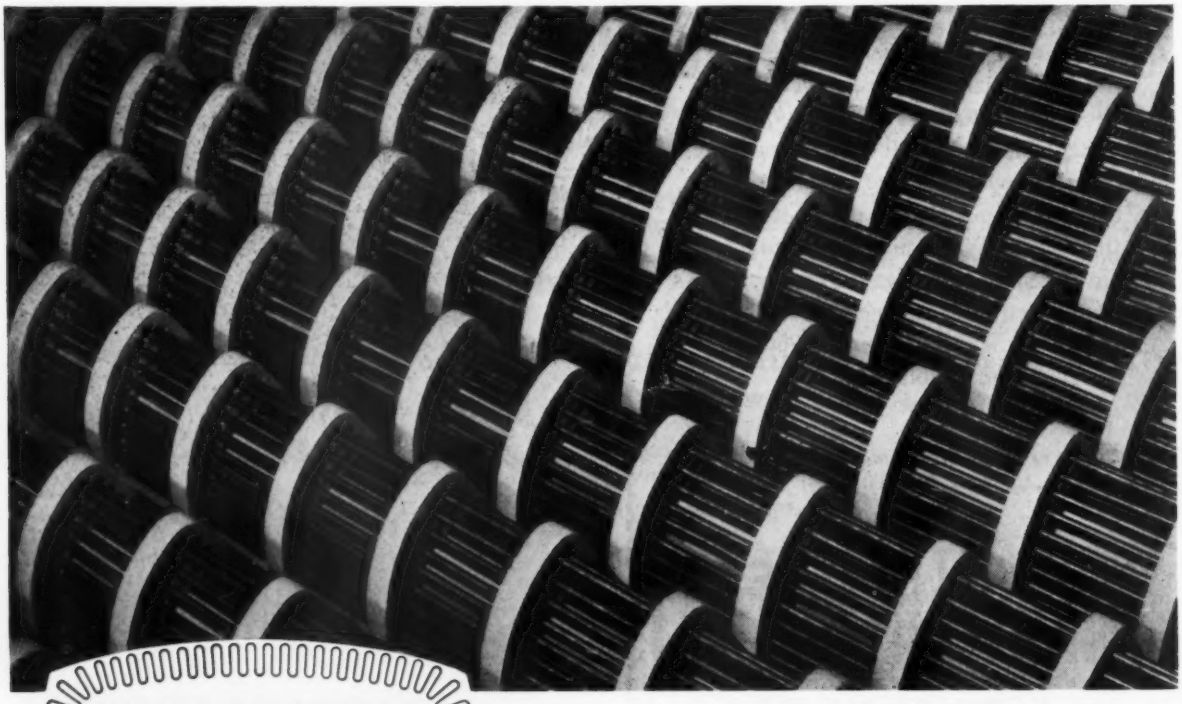

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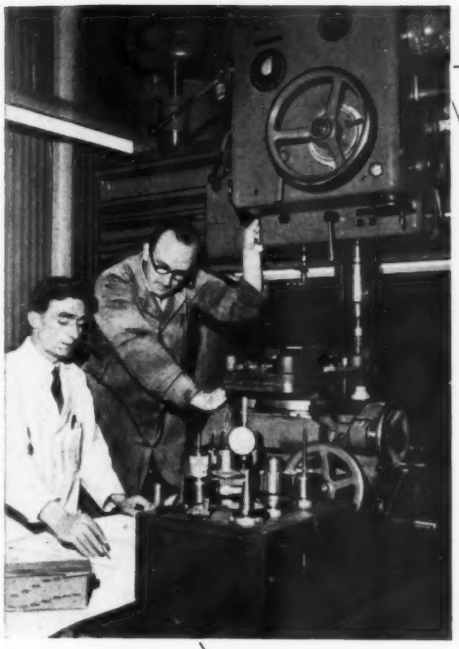

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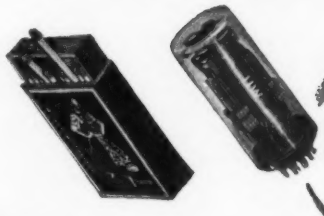

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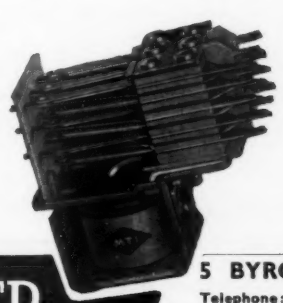

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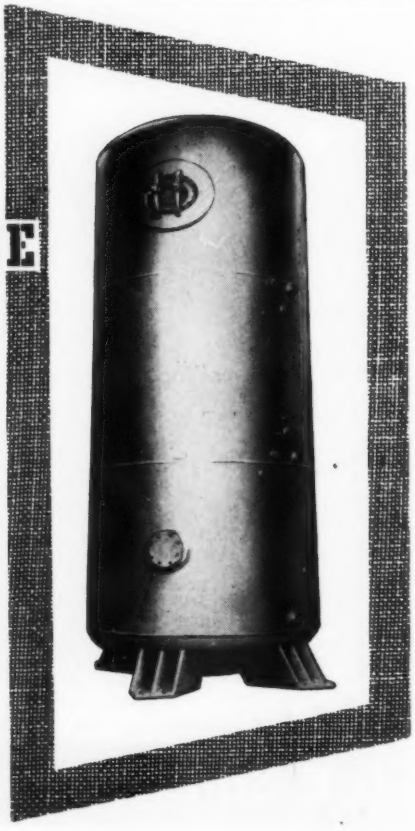

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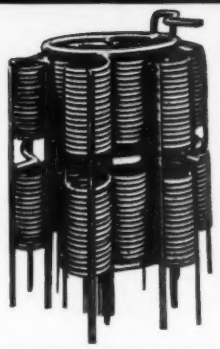

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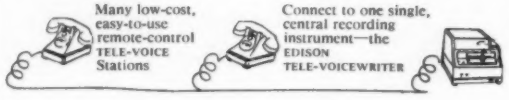
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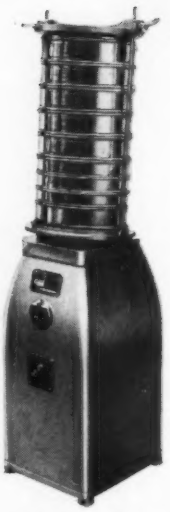

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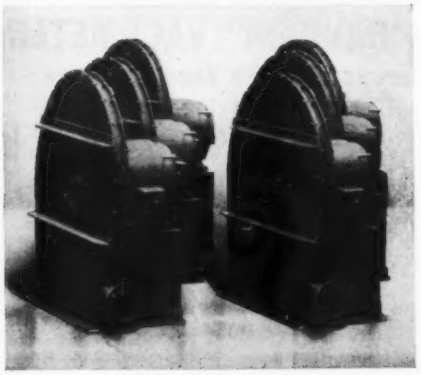

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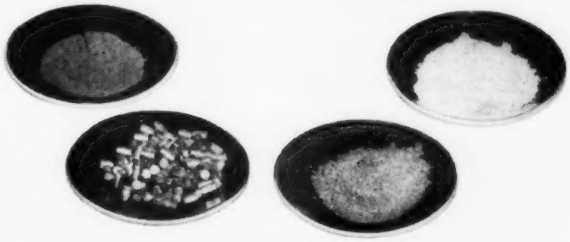

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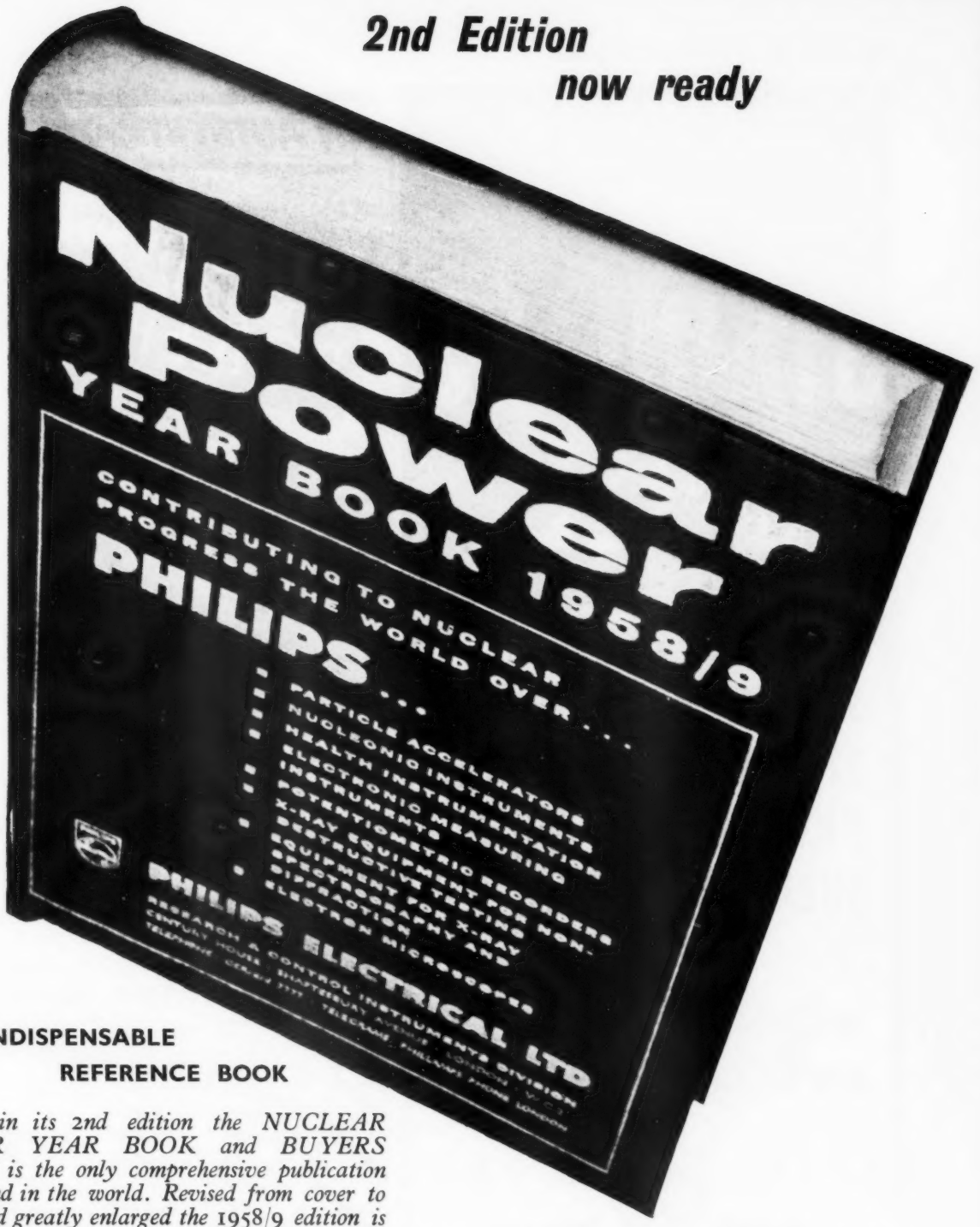

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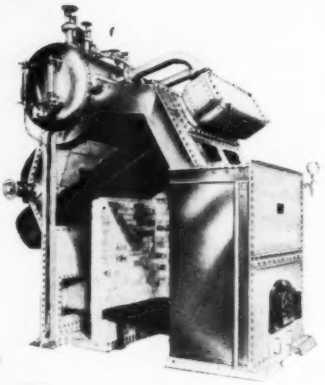

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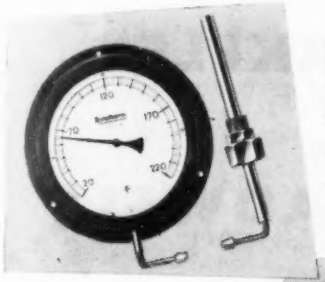

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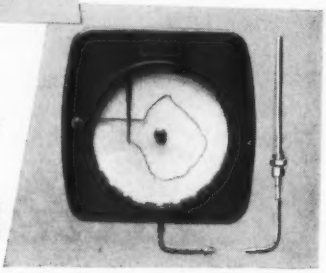

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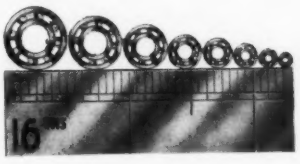

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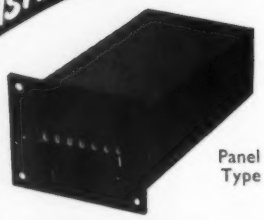

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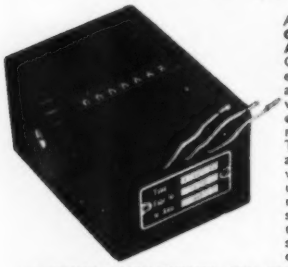

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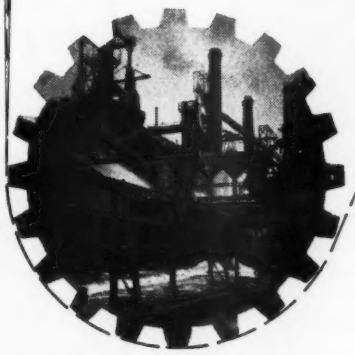

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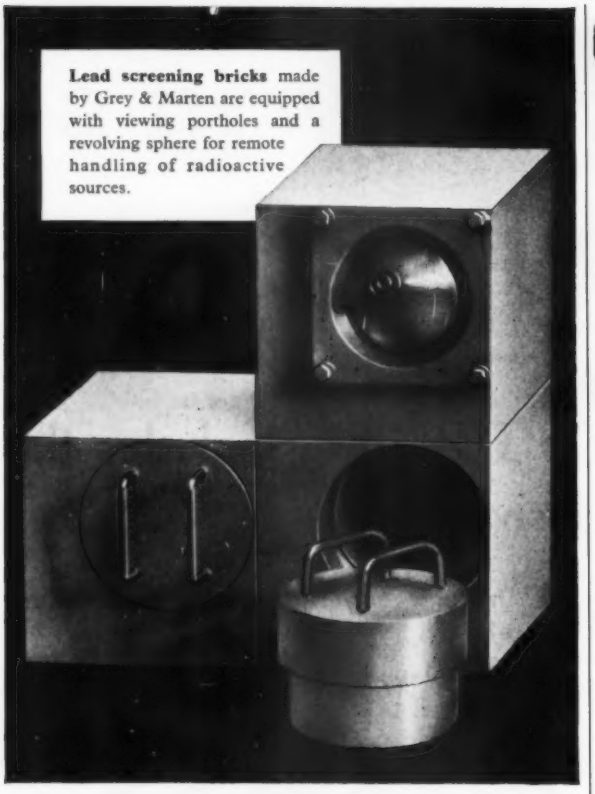

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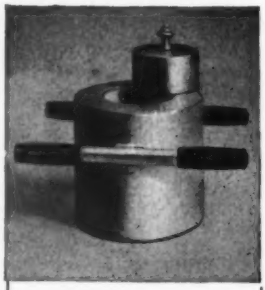

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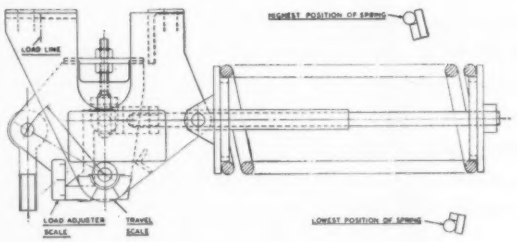

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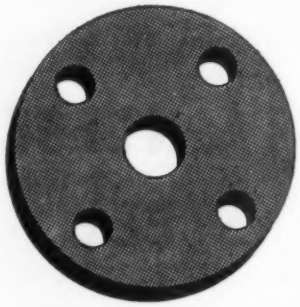

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No. 1 Reactor House, July, 1958

C.E.G.B. Berkeley Nuclear Power Station, being built by A.E.I.-John Thompson Nuclear Energy Company Ltd.

HEAT EXCHANGERS, BERKELEY

The sixteen large heat exchanger (or 'boiler') vessels for Berkeley Nuclear Power Station are now being erected on site by John Thompson.

The vessels, 70 ft. long, 17 ft. 6 in. in diameter and weighing 133 tons, are transported on two bogies from the Berkeley site boiler shop, where fabrication is completed, to their positions adjoining the reactor houses.

JOHN THOMPSON GROUP

Manufacture and installation of these heat-exchanger vessels by John Thompson is so arranged to eliminate the transportation of excessive loads from the works at Wolverhampton and yet to reduce to a minimum the amount of work to be done on site. This is achieved by manufacture of the vessel in sections at the home works and then welding-up the sections to form complete vessels in a site boiler shop specially erected at Berkeley. The site boiler shop accommodates four vessels at a time.

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